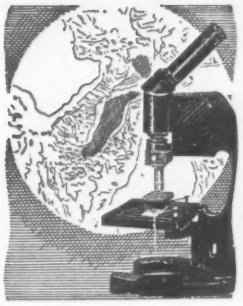
PAPERS AND REPORTS ON RESEARCH AND PRACTICE

Metallurgy • Plant Operation • Research



The Carbon Deposition Reaction over Iron Catalysts

By J. Taylor, M.Sc., Ph.D.

SYNOPSIS

Different iron-oxide preparations react very differently with carbon monoxide during the carbon deposition reaction. The most active preparations can be converted to iron carbide with very little carbon deposition. The products of the reaction under different conditions suggest the following mechanism for the carbon deposition reaction. Carbon is absorbed at the Fe_3O_4/Fe interface to form a supersaturated solid solution which may break down under different conditions to give varying proportions of graphite and iron carbide.

A method for the purification of such graphite is described. A much higher degree of purity is obtained than has been claimed previously. 1164

DESPITE THE INTEREST shown over many years, the mechanism of the reaction $2CO = C + CO_2$ over an iron catalyst is by no means established. Iron,[1] iron percarbide,[2] cementite,[3] and the iron/cementite interface[4] have each been suggested as the active catalyst. This uncertainty is understandable when it is borne in mind that not only are all heterogeneous catalysis reactions difficult to control but in this case the composition of the catalyst is continually changing owing to reaction with carbon monoxide. Experiments carried out some time ago on the preparation of graphite by this reaction form the basis for a suggested new mechanism.

EXPERIMENTAL

The carbon monoxide used in these experiments was prepared from sulphuric acid and sodium formate and washed and dried by passing through dilute alkali and then over calcium chloride. The gas was passed over iron or iron-oxide powders contained in a silica boat in a tube furnace at various definite temperatures. The heating and cooling of the samples was carried out in a stream of pure dry nitrogen. During the experiment the exit gases were metered and analysed for CO_2 content, so that the course of the reaction could be followed by plotting CO_2 content as a function of time (*see* Fig. 1). The solid products of the reaction were examined by means of X-ray powder photographs (9·1-cm camera, CoK_α radiation).

EFFECT OF OXIDE 'HISTORY'

Figure 1 shows that initially the rate of reaction is slow but increases to a maximum and then slowly decreases. This reaction velocity was greatly influenced by the previous history of the oxide used. This is also shown in Fig. 1, where curves A and A_1 were obtained from ferric oxide prepared by calcination of ferric hydroxide at 300° C, whilst for curves B and B_1 the calcination was carried out at 1000° C; A_1 and B_1 were from the same sample of ferric hydroxide prepared by dissolving pure iron powder in hydrochloric acid and precipitating with ammonia. The high-temperature preparations reacted more vigorously than the low-temperature preparations, the maximum rate of reaction being both greater and attained more quickly. However, the reaction diminished, at much the same rate in all cases so that the total amount of carbon deposition may not be very different.

An even more striking example of the difference in activity was obtained in experiments with ferrosoferric oxide. This oxide was prepared by the method of Hilpert and Schacht,[5] in which ferric oxide is reduced at 400° C in anhydrous ammonia or in a hydrogen–steam mixture. When this ferrosoferric oxide was treated with CO at 550° C, the reaction was very rapid, being completed in less than 10 min with no further reaction observed even after 1 h. In this case, too, the product was different. Instead of the swollen black mass obtained in the experiments of Fig. 1, the product was an iron-grey powder; there was a weight decrease of 20% and the X-ray spectrum was that of pure cementite. This result was confirmed in numerous other experiments in which it was found that the experimental conditions were rather critical.

Manuscript received 21st March, 1955.
Dr. Taylor is at the Royal Technical College, Glasgow.

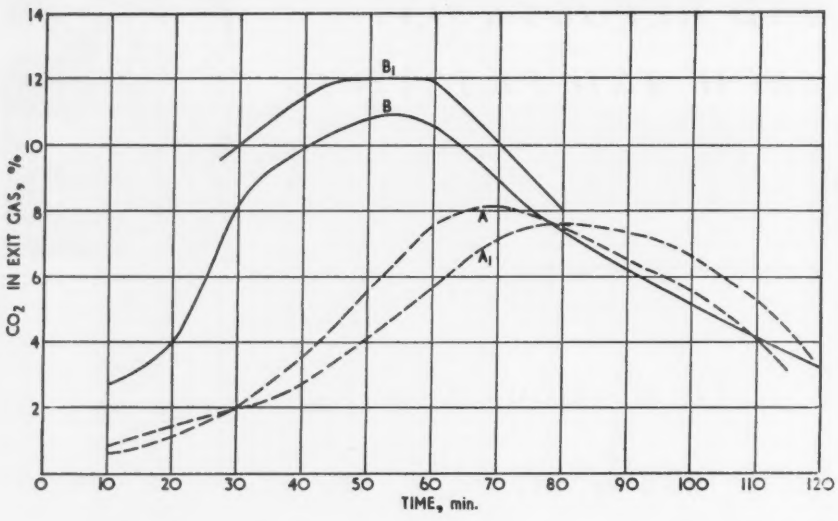


Fig. 1—Course of carbon deposition reaction with pure CO over iron oxide catalysts at 550° C as shown by the percentage of CO_2 in exit gas

Chemical analysis showed that the formation of free carbon was never entirely suppressed even though it could not be detected on the X-ray spectrograph. Limitation of the formation of free carbon depended on keeping the CO_2 concentration in the reaction zone down to a low figure. If larger amounts of the activated oxide or if a slower stream of CO were used, the formation of free carbon proceeded even more vigorously than with the less active oxide preparations.

It was also found that the activation of the oxide was exceedingly difficult to regulate. Activation is not peculiar to ferrosoferric oxide but is only incidental to its preparation. 'Active' ferric oxide, for example, could be obtained by oxidation of the 'active' ferrosoferric oxide at temperatures between 300° and 600° C, γ being formed below 400° C and the α-form above that temperature. This is indeed one of the most convenient methods of preparing γFe_2O_3. The oxides lost their activity on standing, the time required varying from one to eight days with different preparations. This ageing was accelerated by heating to 1000° C in air but not by heating in nitrogen (at least for short periods of time) but attempts to prevent ageing by storing *in vacuo* or in nitrogen were unsuccessful. Activation did not depend on reduction to the exact Fe_3O_4 composition, which corresponds to a 3·3% loss in weight from Fe_2O_3. Different preparations gave weight losses varying from 2% to 7%, although all preparations showed only the Fe_3O_4 X-ray spectrum. The time required for activation varied considerably, from 4 to 20 h, depending not only on the ferric oxide used but also on the time that oxide had been stored.

The importance of the history of the iron oxide on the course of the reaction with CO was further illustrated by the use of oxides prepared by passing steam over pure iron powder at temperatures between 500° and 700° C. The activity of the ferrosoferric oxide so produced increased with decreasing temperature of preparation but was never as high as that of the 'activated' oxide described above. The reaction with oxide so prepared, and CO also, proceeded differently in that the end product was ferrous oxide, with some iron carbide. Furthermore, the proportion of ferrous oxide tended to increase with the more inactive preparations made at high temperatures.

It might also be observed that when a commercial sample of mill scale was treated with CO, ferrous oxide was the only product of the reaction at 700° C.

EFFECT OF TEMPERATURE

In a complex series of reactions such as these, it is difficult to compare reaction rates at different temperatures. The rate and course of the reaction varied with time, with the oxide history, and with the CO_2 concentration in the reaction zone. The last-named is a function of gas flow, particle size, and of the actual reaction which takes place. These limitations apply to the results of other workers,[6, 7] so that whilst there is general agreement that carbon deposition begins at about 350° C, rises to a maximum with increasing temperature, and becomes negligible at about 750° C, there are considerable differences in the exact temperature limits and the temperature of maximum reaction. In these experiments more attention has been given to the effect of temperature on the reaction products than on the other factors. However, subject to the stated limitations, it was found that the temperature range of the reaction was about 400–750° C, with maximum activity at 500–550° C, which is in agreement with Olmer[6] and Baukloh and Hieber.[7] Later experiments indicated that the rate increases again at higher temperatures; for instance, large quantities of graphite were prepared at 850° C. Experiments were carried out on both 'inactive' and ordinary preparations at different temperatures. The results of the X-ray examination of the products are described below and summarized in Table I:

300° C—Both types of ferric oxide were quickly reduced to ferrosoferric oxide but further reaction was too slow to be investigated.

400° C—The rate of reaction was still very slow at

Table I

REACTION PRODUCTS FROM CARBON MONOXIDE ON IRON OXIDE

Temperature, ° C	Intermediate	Final	Remarks
400	Fe_3O_4, $Fe_{20}C_9$		Activated oxide
	Fe_3O_4, $Fe_{20}C_9$, C		Normal oxide
450	Fe_3O_4, $Fe_{20}C_9$	$Fe_{20}C_9$, Fe_3O_4*, Fe*, C*	Activated oxide
		Fe, $Fe_{20}C_9$, C*	Partially activated oxide
500		$Fe_{20}C_9$, Fe_3C*, C*	Activated oxide
		FeC, C, $Fe_{20}C_9$*	Normal oxide
550	Fe_3O_4, Fe_3C	Fe_3C, C*	Activated oxide
	Fe, Fe_3C, Fe_3O_4	Fe, Fe_3C, Fe_3O_4	Partially activated axide
	Fe, C, Fe_3C, Fe_3O_4		Activated oxide higher CO_2 concentration in gas phase
	Fe_3O_4, C, Fe_3C*	Fe_3C, C, Fe_3O_4*	Normal oxide
	Fe, C, Fe_3O_4* Fe_3C*	FeC, C, Fe_3O_4*, Fe*	Normal oxide, higher CO_2 concentration in gas phase
700		Fe_3C, C*	Activated oxide
750–800		Fe_3C, Fe, C*	Activated oxide
850–1000		Fe, Fe_3C, C*	Activated oxide

* Signifies a trace

this temperature. Both oxides gave at first ferrosoferric oxide and an iron carbide, supposedly Fe_3C, previously reported by a number of workers.[8–11] This has since been shown by Jack[12] to have the composition $Fe_{20}C_9$. Further reaction gave the same two products, alone in the case of the active oxide, but with carbon in the case of the normal oxide.

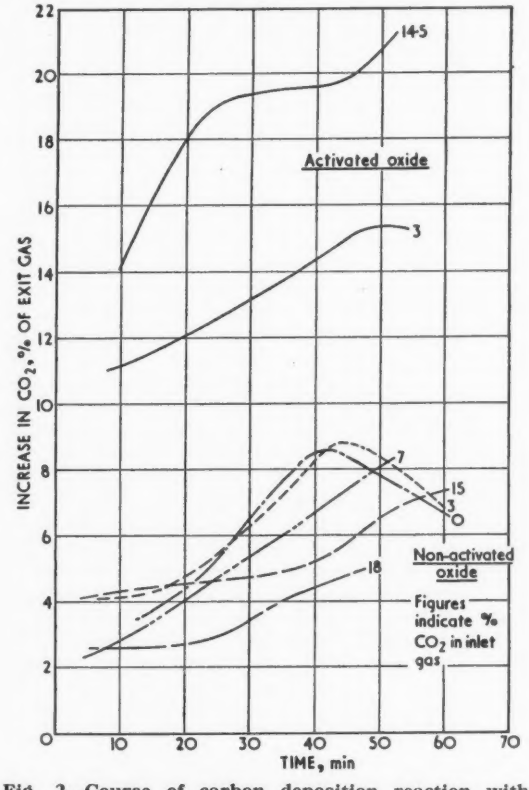


Fig. 2—Course of carbon deposition reaction with CO–CO_2 mixtures over iron oxide catalysts

450° C—The end products were similar to those obtained at 400° C, but the speed of reaction was greater. Three types of oxide were used. After 2–3 h, the normal oxide had been converted to the higher carbide, ferrosoferric oxide, and carbon. 'Active' oxide which had been activated for 20–30 h in ammonia at 400° C was converted to the percarbide with only traces of ferrosoferric oxide and carbon. Oxide which had been activated for only 1–2 h behaved rather differently. Whilst there was a slight trace of free carbon, the product contained metallic iron in addition to the percarbide. The proportion varied and in some cases the product was virtually all metallic iron. This metallic iron was pyrophoric if cooled in CO instead of nitrogen. That the reaction should be completed with metallic iron as a principal product is highly significant, since it discounts the possibility of metallic iron being the active catalyst for carbon deposition.

500° C—The initial product was again ferrosoferric oxide, with the normal oxide; the end products were cementite and a considerable amount of free carbon. With the active oxide the reaction went to completion more rapidly, the end product being mainly the higher carbide with only a little cementite and a very slight trace of carbon.

550° C—The results at this temperature have already been given, i.e. for normal oxide, usually cementite and carbon, but with occasionally a trace of metallic iron; for active oxide, cementite with a trace of carbon.

700° C—At this temperature the reaction with both types of oxide quickly went to completion. The ordinary oxide gave a mixture of cementite and metallic iron with a small amount of graphitic carbon. The active oxide gave cementite with between 0·5% and 1% of carbon as the only impurity.

750–800° C—At these two temperatures active oxide gave cementite and metallic iron, but whereas the former predominated at 750° C the reverse was the case at 800° C. It was shown, however, that if the experiment were continued long enough, this metallic iron could be converted to cementite.

850–1000° C—At 850° C ferric oxide could still be converted into cementite, but above 850° C less and

less cementite was produced; the product was chiefly metallic iron with a little carbon.

REACTION WITH CO–CO_2 MIXTURES

In the case of ' active ' oxide, if the CO_2 concentration was allowed to become too high, there was a very vigorous deposition of free carbon instead of formation of almost pure cementite. To investigate this effect further, a series of experiments was carried out with CO–CO_2 mixtures at 550° C and a gas flow of 8·5 l./h. The general effect of increasing CO_2 concentration can be seen from the curves in Fig. 2. The effect on the rate of the carbon deposition reaction with ordinary oxide is slight until the inlet gas contains about 15% of CO_2, when the rate begins to decrease. It was found difficult to duplicate results with ' active ' oxide, mainly because of a slow progressive change in the activity of the stock iron oxide. However, the results showed that under these conditions carbon deposition was much more vigorous with ' activated ' oxide than with ordinary oxide. X-ray analysis of the products proved interesting. In contrast with the experiments conducted with pure CO, only one of the products from both types of oxide did not contain elementary iron. (In the single exceptional case, ferrous oxide was present instead of iron). This iron is gradually converted to cementite by continued reaction with the CO–CO_2 mixture. In contrast with this result it was shown that iron powder previously treated with hydrogen at 500° C was almost inert to pure CO at 550° C. The same iron treated with a 14% of CO_2–CO mixture caused carbon deposition but the product, in addition to iron, carbon, and cementite, contained ferrosoferric oxide. These experiments cast doubt on the efficacy of iron alone as the catalyst for the reaction. Similar doubt had been cast on the role of cementite and this was confirmed in a series of experiments with cementite between 550° and 850° C. In no case, either with pure CO or with CO–CO_2 mixtures, was any carbon deposition obtained.

PREPARATION OF IRON CARBIDES

Attempts were made to prepare pure iron carbides which, although unsuccessful, are of interest in so far as they bear on the carbon deposition reaction. At first, the problem was to prepare activated iron oxide. This was done by pre-treatment with ammonia at 400° C, but the exact conditions were not easy to specify as they varied not only with different oxide preparations but also with the time of storage. The second problem was to sweep the CO_2 formed from the reaction zone. Reaction was rapid, being virtually complete after 5 min at 700° C, but failure to remove CO_2 rapidly, owing to a too thick layer of oxide or a too low gas velocity, invariably resulted in vigorous carbon deposition. The impurities present in cylinder CO had a similar effect. The most successful preparations still had 0·5–1·0% of carbon in excess of the stoichiometric 6·7%. What the experiments did prove conclusively was that cementite is an end product of the reaction, and although metastable, it does not break down under these conditions, certainly below 700° C and probably not below ~900° C.

Experience with the percarbide was similar except that the product prepared at 450° C was liable to be contaminated with iron as well as carbon. Analysis of the best products showed about 2% of carbon above the theoretical.

Since both carbides are metastable perhaps it is not surprising that the reported effect of temperature shows anomalies. In the present work the percarbide was always the end product in experiments below 500° C and cementite above that temperature. At 500° C, the ordinary oxide gave cementite, whilst activated oxide went mostly to the percarbide but with some cementite. When heated to 500° C in CO the percarbide decomposed to give cementite and graphite. Jack[12] on the other hand, when preparing carbides from nitrides, found that percarbide was formed below 600° C and cementite above. Furthermore, on one occasion graphite prepared in quantity over oxidized iron wire at 850° C was found to contain percarbide. Earlier workers (e.g. Hofmann and Groll,[10] and Hägg[11] on the other hand) reported that the lowest possible temperatures (200–300° C) must be used to minimize the possibility of cementite formation. Evidently, temperature is by no means the only factor in determining which carbide shall form. The ' pressure ' of carbon atoms trying to enter the lattice and, in Jack's method of displacement from the nitride the ' opening up ' of the lattice by an element such as nitrogen, are also important factors.

PURIFICATION OF DEPOSITED CARBON

Graphite prepared from CO on iron has proved unexpectedly difficult to purify—2% of iron after purification has been quoted.[13] A method of purification whereby the residual iron was reduced to 0·1% is described in the Appendix. The chief point of interest with regard to the mechanism of carbon deposition is that it is cementite which is so difficult to remove, despite the fact that free cementite dissolves quite readily in dilute acid.

DISCUSSION

The mechanism of the carbon deposition reaction is best approached by considering the probable course of the reaction at temperatures greater than 723° C. Above this temperature carbon can dissolve in iron to form austenite solid solution. The first step in the reaction is almost certainly adsorption of CO at active centres on the iron surface; decomposition then takes place, the CO_2 formed is desorbed and carbon atoms migrate into the iron lattice. Because of the high free energy of atomic carbon this process can continue and the solution became super-saturated with regard to cementite and also therefore with regard to the stable graphite phase. Under these conditions, both cementite and graphite can crystallize out of the solution. When crystallization takes place during cooling it is normally the metastable but dense cementite which precipitates. However, this takes place in the body of the steel when volume considerations are against the precipitation of the stable but less dense graphite. At the surface, graphite can crystallize freely, and there seems little doubt that most of the carbon does crystallize in this way, but always with a certain proportion of cementite. In addition to the cementite some elementary iron is displaced from the surface and dispersed throughout the graphite. The

dispersed iron can continue to catalyse the reaction, but the cementite is inactive and the catalytic activity diminishes as more and more of the iron is converted into cementite. The resistance of this cementite to chemical attack indicates a close association between it and the graphite. Most probably it is held by the free valency forces at the edges of the graphite layer planes in a type of chemisorption.

The rate of graphite formation must depend on (*a*) the rate of formation and solution of atomic carbon and (*b*) the rate of crystallization of graphite which is a function of the rate of nucleation and the supersaturation of the austenite.

It has been shown[14] that in the carburization of steel with coal gas, 'oxidizing' constituents, e.g. O_2, CO_2, H_2O, accelerate graphite deposition on the surface even to the extent of the carbon content of the underlying metal being less than that of saturated austenite. This increase is associated with a decrease in the iron content of the graphite. The probable effect in this case is that 'oxidizing' gases are adsorbed and form $Fe^{-}O^{-}$ units at the austenite surface. These must influence the stability and the suggestion is that it is decreased. This in turn encourages the crystallization of graphite rather than cementite since the equilibrium carbon solubility is lower for the former. As a consequence, iron rather than cementite is dispersed in the carbon, further carbon deposition can take place on this iron, and the iron content is diluted. Hydrogen has a similar effect in carburization with CO. It has been suggested[15] that hydrogen dissolved in iron can catalyse the reaction. This seems improbable in that coal gas free from 'oxidizing' constituents causes very little carbon deposition. It is more probably due to the formation of some moisture as well as CO_2 by the reaction. There is good evidence[16, 17] to suggest that moisture is more strongly adsorbed than CO_2 on iron catalysts and, therefore, has a similar effect to that of the 'oxidizing' constituents in coal gas. Because of the methane content, coal gas does not form either CO_2 or moisture as a product of the carburization reaction.

There seems little reason to propose a different mechanism for the reaction at temperatures below 723° C, since the products and in particular the properties of the deposited carbon are the same. The difficulty is to envisage how carbon can enter the α-iron lattice to give such a high reaction rate. The answer seems to lie in the observation that ferrosoferric oxide always appeared in the reaction products when carbon deposition was taking place, even when starting from iron instead of iron oxide. Iron ions are more widely spaced both in the oxide lattice and at the oxide/iron interface than in α-iron. Carbon atoms can enter the iron lattice more easily either at the interface or by interchange with oxygen ions during reduction. The supersaturated solution so formed tends to precipitate graphite and iron carbide. The evidence suggests that graphite rather than iron carbide crystallizes at lower levels of supersaturation and iron carbide rather than graphite at higher levels. Carbide formation would then be favoured by a high rate of formation and absorption of carbon atoms and a low rate of nucleation and growth of graphite crystals. Conversely, graphite formation is favoured by a high rate of nucleation and growth and a not too high rate of carbon absorption. According to this scheme, carbon deposition is catalysed by the Fe_3O_4/Fe interface and this interface can result from the reduction of oxide or by reoxidation of iron. The catalyst loses its activity by gradual conversion into iron carbide and/or metallic iron under conditions under which the latter does not reoxidize.

This hypothesis accounts for most of the observed facts. The rapid reaction with activated oxide can cause conversion to carbide with only slight carbon deposition. Percarbide is formed preferentially at lower temperatures irrespective of the type of oxide, but it continues to form at a slightly higher temperature with activated oxide because the higher rate of reaction gives a more supersaturated solution of carbon in iron from which the carbide crystallizes. An increase in the CO_2 content of the gas, or the presence of hydrogen and hence water vapour, gives vigorous carbon deposition with activated oxide. Under these conditions the reaction products show Fe, Fe_3O_4, and Fe_3C at 550° C. The rapid decrease in reaction rate with temperature above 550° C is associated with the more rapid disappearance of Fe_3O_4 and the end products are normally Fe and Fe_3C. It is not so clear why at 400° C iron oxide can be converted into an inactive mixture of iron and iron percarbide. It is also rather puzzling that the same oxide preparation and much the same rate of carbon deposition shows an increase in the proportion of Fe to Fe_3O_4 when the CO_2 content of the reacting gas is increased, although it must be recalled that according to the hypothesis it is the area of the Fe_3O_4/Fe interface and not the relative proportions of Fe_3O_4 and Fe which is important.

The inhibiting effect of ammonia[18] on the reaction can be readily explained through the stabilizing effect of nitrogen and iron–carbon–nitrogen solid solutions. This has been shown by Jack[12] who was able to prepare pure iron percarbide by first preparing the nitride and then replacing the nitrogen with carbon.

The mechanism by which iron oxide is activated by treatment with anhydrous ammonia can only be surmised. By analogy with other solid catalysts it might be expected to be owing to the gradual removal of adsorbed gases giving more active centres for the adsorption of CO. This is not easy to reconcile with the fact that oxide so activated can be oxidized to Fe_2O_3 without loss in activity and that active Fe_2O_3 can be formed by the oxidation of cementite. The fact that Fe_3O_4 produced by the oxidation of iron gives FeO on reduction with CO rather than iron or cementite is surprising. Hilpert and Schacht[5] also found that different preparations of iron oxide treated with chlorine could give different end products but were unable to offer a satisfactory explanation. Two types of spinel structure are known—normal and inverse. The ferrites mostly belong to the latter class although the evidence in the case of magnetite is not conclusive because of the difficulty of distinguishing between the Fe^{2+} and Fe^{3+} ions. Bertant[19] has also shown that the normal and inverse arrangements represent limits and a whole range of intermediate structures are possible. In the case of zinc and copper ferrites the type of structure varies with temperature.

Therefore, there is a possibility that magnetite may also vary in a similar fashion and so account for some of the observed differences but at present there is no evidence that this is so.

APPENDIX

Purification of Carbon Deposited on Iron Catalyst

The difficulty of purifying carbons deposited in this way from iron has been commented on previously. Von Wangenheim[20] was unable to get satisfactory purification either by extraction with acids or by heating in chlorine up to 500° C. Hofmann[2] claimed to have purified deposited carbon by four extractions in boiling 10% HNO_3 but his analyses gave 0·5–3·8% iron in the products. In the present investigation extraction with boiling 50% HCl was first tried. X-ray analysis showed that this readily extracted the ferrosoferric oxide, then more slowly free iron, but the cementite appeared virtually unattacked. This was most surprising because the relatively pure cementite preparations dissolved very easily. Continued extraction in HCl to which strong HNO_3 was added at intervals eventually removed most of the cementite but it was a long and laborious process and involved a considerable loss of carbon.

A better method was required for the purification of large quantities of carbon made in this way. Since cementite was most difficult to remove, conversion of cementite to free iron or iron oxide appeared to be a desirable first step. Three methods were tried to achieve this:

(1) Heating to 1000° C in CO. This caused the cementite to break down into iron and carbon.

(2) Oxidation in CO_2 at 650–750° C. Above 750° C loss of carbon is serious and below 650° C the oxidation is very slow. Ferrosoferric oxide was the product.

(3) Oxidation in air at 300–500° C; this gave ferric oxide.

The third method was the most satisfactory as the ferric oxide dissolved much more easily in 50% HCl than either the free iron or the ferrosoferric oxide. The poor solubility of the iron was probably due to protective bubbles of hydrogen which seemed to dislodge from the mass of carbon only with difficulty. Ferrosoferric oxide formed by oxidation of iron always appears to be unreactive. Air oxidation was very simple with small quantities of material but required care with larger quantities because of a tendency to self-ignition. When the iron content was high the temperature of oxidation must be kept as low as possible, as the iron content decreased the temperature could be gradually increased. By three or four successive oxidations and extractions depending on the initial iron content, carbon was obtained with only 0·1% residual iron.

References to this paper appear on p. 92

The Effect of Quenching on the Thermal Conductivities and Electrical Resistivities of Steel

By

R. W. Powell, D.Sc., Ph.D., F.Inst.P.

SYNOPSIS

Some preliminary experiments are described. Results are given for the effect of water-quenching on the room-temperature electrical resistivities of the series of steels previously investigated in the annealed or stabilized states. Increases of 30% or more were obtained for about half of the steels, and it is believed that the thermal conductivities would undergo comparable reductions. Measurements made on one of the steels confirm that quenching introduces similar changes in both conductivities.

Results are also included for the thermal conductivity and electrical resistivity of an annealed sample of En 31 steel, and electrical resistivity measurements are made on this steel and a 1·22% C steel after oil-quenching to temperatures in the range 135–190° C. These observations suggest that it would be feasible to make thermal conductivity determinations at 150° C on the retained austenite produced when En 31 is quenched to that temperature. The value seems likely to be of the order of 0·18 J cm/cm² s ° C, compared with a value of 0·41 J cm/cm² s ° C obtained for the annealed state. 1255

THE WORK TO BE DESCRIBED in the present paper and the one that follows[1] should be regarded as supplementary to the earlier investigation of the properties of a series of steels[2, 3] carried out in the Physics Division of the National Physical Laboratory, and subsequently published in booklet form.[4]

The 22 steels had been supplied and tested in conditions for which their properties were relatively stable and independent of the heating treatments associated with the various tests. The carbon, low-alloy, and 18·45% W steels had all been annealed at temperatures of 800–930° C which were above the transformation region ; the two steels of about 13% Cr content had been heated at 960° C in air, tempered 2 h at 750° C, and air-cooled, while the 13% Mn steel, 28·37% Ni steel, and 19·11% Cr–8·14% Ni steel had been heated to 1050°, 950°, and 1100° C respectively. The first-named were cooled in air, and the other two were cooled in water.

The physical constants given for these steels in the

Paper MG/N/162/55 of the Thermal Treatment Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received on 28th November, 1955. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Dr. Powell is with the Physics Division of the National Physical Laboratory.

publications already mentioned relate therefore to the steels when in these relatively stable conditions.

After the work described in Part II had been completed,[3] some attention was directed to an examination of the influence of quenching on the physical properties of certain steels. An account of the specific heat measurements, which were made about the same time on the 1·22% C steel and on the additional ball-race steel En 31, has already been published.[5] The present paper details some electrical resistivity measurements which were made at that time on these two steels during O.Q., and shows the effect of W.Q. on the room-temperature resistivity of ¼-in. dia. rods of each of the series of steels previously studied. Similar observations were also made on some of the steels in the form of 1-in. dia. rods, and for one of these, steel No. 20, thermal conductivity determinations were made for the W.Q. state.

Subsequently, on behalf of the Thermal Treatment Committee of The British Iron and Steel Research Association, determinations of both thermal and electrical conductivities have been made after O.Q. and tempering at various temperatures for three further steels, En 8, En 19, and a steel somewhat resembling En 31. This section of the work is dealt with in the accompanying paper.[1]

The subject is one which does not appear to have received much earlier attention, the only thermal conductivity measurements observed on quenched and tempered steels being those of Hattori[6] and Kikuta,[7] and neither worker included values for the electrical conductivity.

Table I

ELECTRICAL RESISTIVITIES ($\mu\Omega$ cm²/cm) AT 20° C BEFORE AND AFTER QUENCHING ¼-in. RODS IN WATER

Steel No. as given in		Main constituents, %	Electrical resistivity		
Refs (2), (3)	Ref (4)		Initial	After quenching	Increase %
		Carbon steels			
1	1	0·06 C, 0·38Mn	12·8$_1$	13·0$_6$	1·9
2	2	0·08 C, 0·31 Mn	14·0$_8$	14·3$_8$	2·1
3	3	0·23C, 0·635Mn	16·5$_3$	17·8$_9$	8·2
5	4	0·415C, 0·643Mn	16·8$_8$	21·8$_7$	29·6
6	5	0·435C, 0·69Mn	18·7$_0$	24·7$_1$	32·1
7	6	0·80C, 0·32Mn	17·8$_2$	33·9$_5$	90·4
101	7	0·84C, 0·24Mn	17·3$_9$	31·4$_9$	81·1
8	8	1·22C, 0·35Mn	20·2$_5$	32·1$_8$	58·9
		Low-alloy steels			
4	9	0·23C, 1·51Mn	20·8$_2$	24·5$_2$	17·8
9	10	0·325C, 0·17Cr, 3·47Ni	27·0$_0$	31·5$_2$	16·7
10	11	0·33C, 0·80Cr, 3·38Ni	26·8$_8$	34·8$_7$	29·6
11	12	0·325C, 0·71Cr, 3·41Ni	28·1$_0$	35·7$_0$	27·0
12	13	0·34C, 0·78 Cr, 3·53Ni	28·9$_7$	37·9$_1$	30·8
19	14	0·315C, 0·69Mn, 1·09Cr	21·1$_4$	27·5$_9$	30·5
20	15	0·35C, 0·59Mn, 0·88Cr, 0·26Ni	22·2$_7$	29·6$_9$	33·3
21	16	0·485C, 1·98Si, 0·90Mn	42·9$_7$	49·5$_6$	15·3
		High-alloy steels			
13	17	1·22C, 13·0Mn	68·6$_3$	69·1$_0$	0·7
14	18	0·28C, 0·89Mn, 28·37Ni	85·5$_3$	84·9$_0$	–0·7
15	19	0·08C, 19·11Cr, 8·14Ni	70·7$_8$	70·9$_3$	0·2
16	20	0·13C, 12·95Cr, 0·14Ni	50·7$_5$	56·1$_9$	10·5
17	21	0·27C, 13·69Cr, 0·20Ni	52·7$_4$	62·3$_1$	18·1
18	22	0·715C, 4·26Cr, 18·45W	42·2$_4$	53·5$_2$	26·7

Table II

HARDNESS VALUES

Steel No. as in Refs (2), (3)	3	5	7	101	8	9	10	11
D.P.N. near centre	328	660	890	890	876	655	677	663
D.P.N. near edge	317	666	897	876	883	652	666	665

Electrical Resistivity Measurements on W.Q. Steels

The tests were made on 4-in. lengths of ¼-in. dia. rod. Initial measurements of the electrical resistivity of each sample at normal temperatures were made using for potential contacts a pair of knife edges rigidly mounted to give a potential length of 5 cm. The carbon, low-alloy, and high-alloy steel specimens were then tied together for treating in three separate bundles. These were slipped into a closed-ended alumina tube which could be evacuated and heated to about 950° C. After being at this temperature for about 1 h, the austenitized specimens were quickly transferred from the tube and plunged into water at room temperature. The resistivities of each rod at normal temperature were then redetermined. The results obtained are given in Table I after adjusting to a temperature of 20° C.

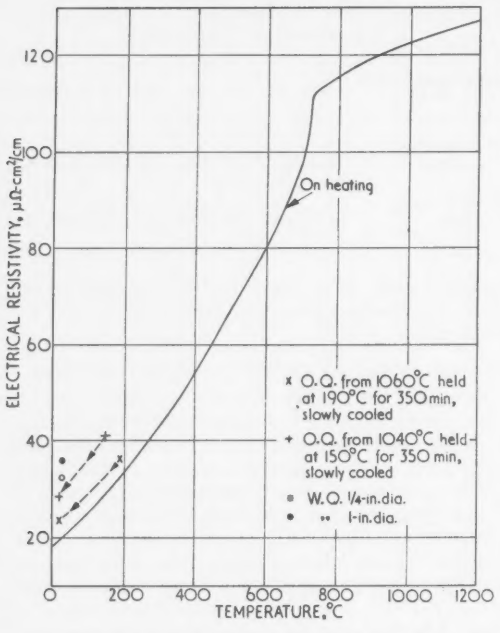
The percentage increase is seen to be greatest for the 0·8 C steel and for the steel of the eutectoid composition. Nine others gave increases of the order of 30% or more. It is realized that the W.Q. treatment was rather drastic and some of the specimens had developed longitudinal cracks as a result of the severe stresses associated with the treatment. The measurements do, however, serve to show the reductions in electrical conductivity likely to be brought about by rapid cooling of these steels from temperatures above their transformation points. It is shown later that the thermal conductivity suffers a fairly comparable decrease, and that values for this quantity can be estimated from those for the electrical resistivity.

Diamond pyramid hardness measurements made on cross-sections cut from some of the W.Q. bars gave the values given in Table II, from which there will be seen to be some correlation between these values and the increase in resistance on quenching.

Table III

ELECTRICAL RESISTIVITIES ($\mu\Omega$ cm²/cm) AT 20° C AFTER QUENCHING 1-in. AND ¼-in. DIA. BARS IN WATER

Steel No. as in Refs (2), (3)	1-in. bar	¼-in. bar
7	23·9	33·9$_5$
8	35·8	32·1$_8$
17	60·2$_5$	62·3
18	54·5$_5$	53·5
20	29·7	29·6$_9$


ELECTRICAL RESISTIVITY, μΩ-cm²/cm
TEMPERATURE, °C
On heating
x O.Q. from 1060°C held at 190°C for 350 min, slowly cooled
+ O.Q. from 1040°C held at 150°C for 350 min, slowly cooled
W.Q. 1/4-in.dia.
1-in.dia.

Steel No. 8: 1·22% C, 0·16% Si, 0·35% Mn, 0·015% S, 0·009% P, 0·11% Cr, 0·13% Ni, 0·01% Mo, 0·077% Cu

Fig. 1—Resistivity on heating and quenching. Steel No. 8

Five of the 1-in. dia. specimens originally used for the thermal conductivity determinations were also tested. Each bar was coated to prevent oxidation, heated in air to about 1000° C and then quenched in water.

From the values given in Table III, the final room temperature resistivities of these bars can be compared with the results for the $\frac{1}{4}$-in. bars.

Steel No. 7 did not appear to have hardened completely in the larger size, but for the other steels the two sets of values are fairly comparable.

Table IV

THERMAL CONDUCTIVITY (J cm/cm² s °C), ELECTRICAL RESISTIVITY (μΩ cm²/cm) AND LORENZ FUNCTION (J Ω/s °C °K) OF STEEL NO. 20 FOR THE ANNEALED STATE AND AFTER O.Q. AND TEMPERING AT 100° C

Temperature, °C	Annealed state			O.Q. and tempered at 100° C		
	Thermal conductivity	Electrical resistivity	$10^8 \times$ Lorenz function	Thermal conductivity	Electrical resistivity	$10^8 \times$ Lorenz function
20	...	22·3	...	...	29·3	...
30	$0·43_5$	22·8	3·3	$0·34_5$	29·8	3·4
80	$0·43_5$	25·8	3·2	0·35	33·2	3·3

Table V

THERMAL CONDUCTIVITY (J cm/cm² s °C), ELECTRICAL RESISTIVITY (μΩ cm²/cm) AND LORENZ FUNCTION (J Ω/s °C °K) FOR A 1-in. DIA. SAMPLE OF ANNEALED STEEL En 31 (C 1·06%, Si 0·24%, Mn 0·045%, S 0·013%, P 0·017%, Cr 1·46%, Ni 0·31%, Fe Balance)

Temperature, °C	Thermal conductivity	Electrical resistivity	$10^8 \times$ Lorenz function
50	$0·41_5$	24·9	3·2
100	0·41	28·1	3·1
150	0·41	31·7	3·1
200	$0·40_5$	35·6	$3·0_5$
300	$0·39_5$	44·0	$3·0_5$
400	$0·37_5$	54·6	$3·0_5$
500	$0·35_5$	66·5	$3·0_5$
600	$0·32_5$	80·0	3·0
700	0·30	95·5	$2·9_5$
800	0·24	113·5	$2·5_5$

Thermal Conductivity of Steel No. 20 for the Quenched State

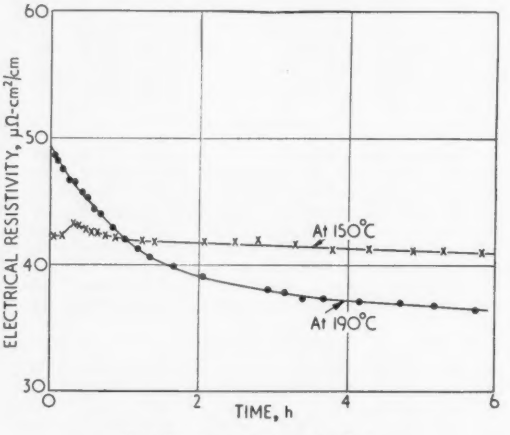
As steel No. 20 was one which appeared likely to have hardened uniformly in the 1-in. dia. bar, a thermal conductivity determination was undertaken by the usual longitudinal heat-flow method. Before testing, the bar was tempered at 100° C by immersion in boiling water for some hours. This treatment caused the electrical resistivity at 20° C to decrease to 29·3 μΩ cm²/cm.

The results obtained for this condition of the steel are given in Table IV, in which values for the annealed state are included for comparison.

At 30° C, the thermal conductivity will be seen to have decreased by about 21% compared with a decrease of about 23% in the electrical conductivity. These changes are reasonably comparable.

Electrical Resistivity Measurements on O.Q. Steels

With a view to ultimately determining the thermal conductivity of the retained austenite in suitable steels which had been O.Q. to temperatures of the



Steel No. 8, composition as in Fig. 1

Fig. 2—Resistivity/time after O.Q. from 1065° and 1040° C to 190° and 150° C respectively. Steel No. 8

order of 150–190° C, preliminary observations were made of the corresponding electrical resistivity change. Two steels were studied, steel No. 8 of the present series and steel En 31 (the steels used by Griffiths and Pallister).[2]

The test samples were in the form of $\frac{1}{4}$-in. dia. rods about 4 in. long. Each specimen was fitted with chromel/alumel thermocouples, which also served as potential leads, and attached to $\frac{1}{16}$-in. steel rods which served as current leads and supports. These steel rods were threaded through a rubber bung which fitted into one end of the furnace tube. The latter was wound with kanthal wire, and its two ends projected from the furnace and remained cool. One end was connected to a vacuum pump, and the bung carrying the specimen leads was sealed into the other end.

Electrical resistance measurements could be made during heating and whilst steadying at the final temperature. Meanwhile an oil bath had been heated and controlled at the required quenching temperature. The specimen could be quickly removed from the furnace and plunged into the oil bath. Observations of its resistance were then made at noted times.

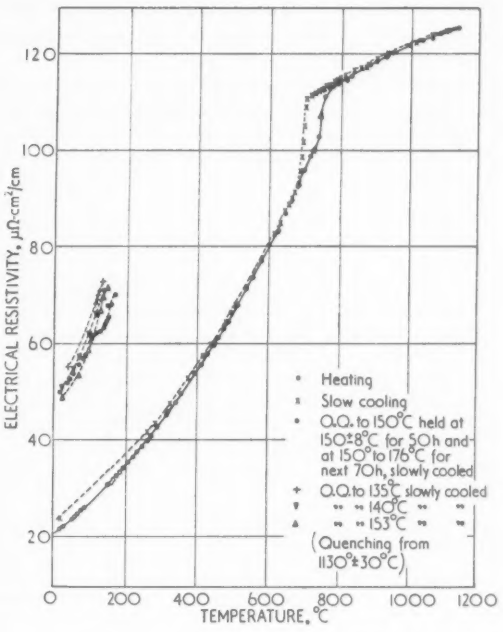
The results obtained are shown in the accompanying figures.

In Fig. 1, the resistance/temperature curve obtained on heating steel No. 8 is reproduced, and the results of two O.Q. experiments are indicated. In one experiment the sample was quenched from 1065° C and held at about 190° C for 350 min when the heat to the oil bath was switched off and the room-temperature resistance measured on the following day. A similar procedure was followed in the other experiment except that the oil bath was then at 150° C.

Figure 2 indicates the variation of the resistance with time whilst the oil bath was held at 190° C and 150° C respectively. The change of resistance with time is seen to be smaller at the lower temperature.

The martensitic point for a 1·22% plain carbon steel is about 140° C. From the foregoing results it would appear that, the nearer the quenching temperature approaches to the martensite point, the more stable is the austenite retained in the quenched steel.

The En 31 steel had been selected as one for which the austenite retained at 150° C would be likely to be more stable. This certainly proved to be the case, for on quenching from 1100° C to oil at 150° C, the resistivity decreased to a value of 71·5 μΩ cm²/cm and remained within $\frac{1}{2}$% of this value for the 50 h that it was held at that temperature. The results of the electrical resistivity measurements made on this steel are given in Fig. 3, and these include those made on heating to 1130° C followed by slow cooling, as well as the observations made after quenching from about 1130° C to temperatures of about 150°, 140°, and 135° C respectively. The first quenching experiment at 150° C was that already mentioned. After remaining at about this temperature for 50 h, the bath temperature was allowed to rise to 176° C and held there for another 70 h. This treatment caused the resistivity to fall to 70·4 μΩ cm²/cm, which on returning to 152° C fell further to 67·8 μΩ cm²/cm. On switching off and allowing the temperature of the bath to fall to room temperature the further values included in the figure were obtained. These gave a reduced



Steel En 31: 1·06% C, 0·24% Si, 0·495% Mn, 0·013% S, 0·017% P, 1·46% Cr, 0·31% Ni

Fig. 3—Resistivity on heating, slow cooling, and O.Q. steel En 31

rate of change of resistivity with change in temperature in the region of 130° to 110° C. No corresponding behaviour is observed in the other three curves, which were all obtained by cooling the oil bath immediately after the rod had been quenched. Should this flat portion be associated with the formation of martensite, its absence in these later experiments seems difficult to understand. There is clearly scope for further investigation.

So far as the work had gone, it has indicated that thermal conductivity measurements on the austenite retained at about 150° C should be possible for either steel No. 8 or En 31, but care would need to be exercised to avoid heating much above 150° C or cooling below about 140° C. The experiment would involve some technical difficulties and a suitable opportunity for attempting this item has not yet occurred. Thermal conductivity determinations by normal methods have, however, been undertaken on the En 31 steel when in the annealed state, and these results have been included in an earlier publication.[8] Complete results for the thermal conductivity, electrical resistivity, and Lorenz function of the annealed En 31 steel are given in Table V.

Assuming the same Lorenz function for the quenched as for the annealed steel, the thermal conductivities of steel No. 8 and the En 31 steel at 150° C and in the O.Q. state would be $0{\cdot}29_5$ and $0{\cdot}18_5$ J cm/cm² s °C respectively, compared with values of 0·45 and 0·41 J cm/cm² s °C for the annealed state.

These differences in thermal conductivity are sufficiently great to justify further thermal conductivity measurements being made on quenched steels. Furthermore, the differences in the particular cases treated above may prove to be somewhat underestimated, since there is evidence for the Lorenz function of steels in the austenitic state being lower than for steels in the ferritic state.[9, 10]

Acknowledgments

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

The author desires to acknowledge the assistance rendered by Miss N. Beer, B.Sc., who assisted with much of the observational work.

References

1. R. W. POWELL and R. P. TYE: *J. Iron Steel Inst.*, 1956, vol. 184, pp. 10–17 (this issue).
2. Second Report of Alloy Steels Research Committee, *Iron Steel Inst. Spec. Rep.* No. 24, pp. 215–251, 1939.
3. *J. Iron Steel Inst*, 1946, vol. 154, No. 2, pp. 83P–121P.
4. " Physical Constants of Some Commercial Steels at Elevated Temperatures." Ed. British Iron and Steel Research Association, 1953, London, Butterworth.
5. E. GRIFFITHS and P. R. PALLISTER: *J. Iron Steel Inst.*, 1953, vol. 175, pp. 30–32.
6. D. HATTORI: *Ibid.*, 1934, vol. 129, No. I, pp. 289–306.
7. T. KIKUTA: *Tetsu-to-Hagane*, 1938, vol. 24, pp. 524–528.
8. R. W. POWELL: *Research*, 1954, vol. 7, pp. 492–501.
9. R. W. POWELL: *J. Iron Steel Inst.*, 1946, vol. 154, No. 2, pp. 116P–121P.
10. R. W. POWELL: *Iron Steel Inst. Spec. Rep.* No. 43, pp. 315–318, 1952.

The Effect of Oil Quenching and Tempering on the Thermal Conductivities and Electrical Resistivities of Three Steels

By R. W. Powell, D.Sc., Ph.D., F.Inst.P. and R. P. Tye

THE PRESENT PAPER relates to an investigation made on behalf of the Thermal Treatment Committee of the British Iron and Steel Research Association. As explained in the foregoing paper[1] this work is to some extent supplementary to earlier investigations

Paper MG/N/202/55 of the Thermal Treatment Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received on 28th November, 1955. The views expressed are the authors', and are not necessarily endorsed by the Committee as a body.

Dr. Powell and Mr. Tye are with the Physics Division of the National Physical Laboratory.

SYNOPSIS

A detailed investigation has been made of the influence of oil-quenching and tempering on thermal conductivities and electrical resistivities of 3 steels, En 8, En 19, and a high-C, Cr–Mo steel of En 31 type. The conductivity is reduced by O.Q., the amount of the reduction ranging from about 20% to 50% and increasing in the order in which the steels are listed. Tempering increases the conductivity and for each steel a maximum conductivity is obtained after tempering at an optimum temperature of about 100° C below the transformation temperature. Heat-treatment of the annealed steel in the same temperature range also leads to similar but slower increases in conductivity, and the hardness falls a little below the low annealed value. For the tempered steel, however, the maximum conductivity can be attained whilst the steel retains some of the hardness due to the O.Q. This result may be of importance for certain applications of the steels.

For the various conditions the Lorenz functions only range from $3{\cdot}1 \times 10^{-8}$ to $3{\cdot}4 \times 10^{-8}$ J ohm/s ° C °K, so that the thermal conductivities can be derived to within about 5% from electrical resistivity measurements. 1256

Table I

CHEMICAL ANALYSES OF STEELS TESTED, WEIGHT-%

Type of Steel	C	Si	Mn	S	P	Cr	Ni	Mo
High C, Cr–Mo (En 31 type)	1·05	0·23	0·73	0·028	0·030	1·5	0·23	0·21
En 8	0·39	0·14	1·05	0·043	0·032	...	0·12	...
En 19 (¼-in. rod)	0·42	0·30	0·65	0·029	0·037	1·02	0·27	0·33
En 19 (tube)	0·42	0·23	0·59	0·019	0·046	1·15	0·33	0·22

undertaken at the National Physical Laboratory[2, 3, 4] for the same Committee, in that the former measurements all related to steels when in the relatively stable condition obtained by annealing or comparable treatments. In view of the marked influence which quenching has on the properties of many steels, it was considered desirable to undertake a detailed study of the effect of quenching on the thermal and electrical conductivities of a few steels and to include an investigation of the changes brought about by subsequent tempering treatments.

The first steel studied was a high-C, Cr–Mo steel of En 31 type. The specimens were supplied in two sizes, 8 in. long by 1 in. dia., and 4 in. long by ¼ in. dia. These specimens were stated to have been O.Q. from a temperature of 830° C and to have been tempered at temperatures of 140°, 350°, 550°, and 750° C.

The two other steels tested were samples of En 8 and En 19. The En 8 steel was supplied from the B.I.S.R.A. Metallurgical (General) Divisional Laboratory in the form of a 1½-in. dia. bar, 2 ft 6 in. long, marked CMK1 and was stated to be in the normalized condition.

The samples of En 19 steel were supplied by Messrs. Brown Bayley Steels Ltd., in the form of rods 6 in. long by ¼ in. dia. Two were in the fully-annealed condition, and two as-hardened. Later, a further specimen was supplied for the thermal conductivity measurements. This was in the form of a tube 8 in. long, 1 in. external dia., and ¾ in. internal dia.

For these steels, En 8 and En 19, the quenching and tempering treatments were carried out by the Metallurgy Division, N.P.L. Suitable precautions were at all times taken to avoid chemical changes during treatment. After tempering, the samples were furnace cooled, and hardness measurements and photomicrographs taken.

The analyses of the steels are given in Table I.

In Table II the details supplied with the specimens of high-carbon, chromium–molybdenum steel are tabulated.

METHODS OF EXPERIMENT

The high-C, Cr–Mo steel was chosen as it could be expected to harden throughout a specimen of 1-in. dia., and the agreement obtained for the hardness measurements made on the two sizes of specimen confirmed this.

For this steel, room-temperature electrical resistivity measurements were first made on each specimen using the straightforward method in which the potential drop on the rod is compared with that produced by

Table II

INFORMATION SUPPLIED WITH SPECIMENS OF HIGH-CARBON CR–MO STEEL

Identification No.	Tempering Temperature, °C	Tempering Time, h	Hardness, D.P.N.
1*a* (1 in. dia.)	140	6	820
1*b* (½ in. dia.)	140	6	800
2*a* (1 in. dia.)	750	2	240
2*b* (½ in. dia.)	750	2	240
3*a* (1 in. dia.)	350	3	625
3*b* (½ in. dia.)	350	3	625
4*a* (1 in. dia.)	550	4	440
4*b* (½ in. dia.)	550	4	440

Table III

THERMAL CONDUCTIVITY (J cm/cm² s ° C), ELECTRICAL RESISTIVITY (μΩ cm²/cm), AND LORENZ FUNCTION (J Ω/s ° C ° K) OF O.Q. AND TEMPERED HIGH-C, Cr–Mo STEEL

Sample No.	Condition	Temperature, °C	Thermal Conductivity	Electrical Resistivity	$10^8 \times$ Lorenz Function
1*a*	O.Q., Tempered 140° C	0	$0{\cdot}22_5$	$37{\cdot}_5$	3·1
		20	...	$39{\cdot}_0$	...
		50	$0{\cdot}24_3$	$41{\cdot}_6$	$3{\cdot}1_5$
		100	$0{\cdot}25_7$	$44{\cdot}_8$	3·1
3*a*	O.Q., tempered 350° C	0	0·32	$28{\cdot}_7$	$3{\cdot}3_5$
		20	...	$29{\cdot}_5$	...
		50	$0{\cdot}33_5$	$31{\cdot}_8$	3·3
		100	0·34	$35{\cdot}_2$	3·2
		150	$0{\cdot}34_5$	$38{\cdot}_7$	$3{\cdot}1_5$
		200	$0{\cdot}34_5$	$42{\cdot}_7$	3·1
		250	$0{\cdot}34_5$	$46{\cdot}_8$	3·1
		300	0·34	$51{\cdot}_2$	$3{\cdot}0_5$
4*a*	O.Q., tempered 550° C	0	$0{\cdot}33_5$	$24{\cdot}_6$	3·2
		20	...	$25{\cdot}_6$	...
		50	$0{\cdot}37_5$	$27{\cdot}_5$	3·2
		100	0·39	$30{\cdot}_7$	3·2
		150	0·39	$34{\cdot}_3$	$3{\cdot}1_5$
		200	$0{\cdot}38_5$	$38{\cdot}_3$	3·1
		250	$0{\cdot}37_5$	$42{\cdot}_5$	$3{\cdot}0_5$
		300	0·37	$47{\cdot}_2$	$3{\cdot}0_5$
		350	0·36	$52{\cdot}_0$	3·0
		400	$0{\cdot}35_5$	$57{\cdot}_2$	3·0
2*a*	O.Q., tempered, 750° C	0	$0{\cdot}37_5$	$23{\cdot}_6$	$3{\cdot}2_5$
		20	...	$24{\cdot}_4$	...
		50	$0{\cdot}39_5$	$26{\cdot}_7$	$3{\cdot}2_5$
		100	$0{\cdot}40_5$	$30{\cdot}_0$	$3{\cdot}2_5$
		150	$0{\cdot}40_5$	$33{\cdot}_8$	$3{\cdot}2_5$
		200	0·40	$38{\cdot}_0$	3·2
		250	0·39	$42{\cdot}_3$	$3{\cdot}1_5$
		300	0·38	$47{\cdot}_2$	$3{\cdot}1_5$
		350	$0{\cdot}37_5$	$52{\cdot}_0$	$3{\cdot}1_5$
		400	$0{\cdot}36_5$	$57{\cdot}_2$	3·1
		450	$0{\cdot}35_5$	$62{\cdot}_8$	3·1
		500	$0{\cdot}34_5$	$68{\cdot}_7$	$3{\cdot}0_5$
		550	0·33	$75{\cdot}_2$	3·0
		600	0·32	$82{\cdot}_1$	3·0
		650	0·30	$89{\cdot}_5$	2·9
		700	$0{\cdot}28_5$	$97{\cdot}_2$	$2{\cdot}8_5$
		750	$0{\cdot}25_5$	$109{\cdot}_0$	2·7
		800	$0{\cdot}24_5$	$114{\cdot}_8$	2·6
		850	0·25	$117{\cdot}_2$	2·6
		900	$0{\cdot}25_5$	$118{\cdot}_7$	2·6

Table IV

ELECTRICAL RESISTIVITY ($\mu\Omega$ cm²/cm) OF SAMPLES OF En 8 STEEL AT 20° C, WHEN IN THE NORMALIZED AND O.Q. STATES

Sample No.	Dia., in.	Condition		Resistivity increase, %
		Normalized	O.Q.	
1*a*	1	21·2$_5$	...	...
2*a*	1	21·1	21·7	2·8
1*b*	¼	21·1	...	...
2*b*	¼	21·1	25·0$_5$	18·7
2*c*	⅛	21·3	26·0	22·1

the same current across a resistance of known and comparable value.

For most of the thermal conductivity determinations, the usual method[2, 3] was used in which the temperature gradient established in a 1-in. dia. bar is compared with that in a similar bar of metal of known thermal conductivity to which it is joined. Throughout these tests care was usually taken not to heat any part of the working section of the test bar above the tempering temperature to which it had been subjected. In the case of sample No. 2*a* of the high-C, Cr–Mo steel, however, the measurements were continued to well above the tempering temperature of 750° C, a maximum mean temperature of 925° C being reached.

Thermal conductivity determinations at mean temperatures below about 40° C are not readily made by this method, since the low-temperature end of the bar is water-cooled. The results obtained for the high-C, Cr–Mo steel at low temperatures were of interest in that maximum values were indicated at about 100° C. An independent method was therefore used which enabled measurements to be obtained down to about 7° C. These served to confirm the earlier indications and by extrapolation gave the 0° C values of Table III.

For these additional measurements the following method was used.

A heating coil fitted with current and potential leads was enclosed in the cavity at the top of the bar and thermocouples were attached along the length of the bar as before, and to the top plate covering the heater. In the first stage of the experiment, the base of the bar was in good thermal contact with the base of a cylindrical metal vessel containing the specimen. This vessel was nickel plated and polished on the inner surface. It could be evacuated to a pressure of less than 1μ, the leads and thermocouples being brought out through waxed seals. The metal vessel was kept surrounded by melting ice in a large Dewar flask. When equilibrium had been obtained it was assumed that the measured energy supplied to the heater contributed to the radiation loss from the entire surface of the specimen and to the heat conducted through the specimen to the base. A second experiment, conducted in a similar manner, but with the specimen hanging freely in the enclosure, enabled a correction for the radiation loss to be determined.

Electrical resistivity measurements were made on all thermal conductivity samples over the full range of temperature, either in the course of the same experiment, or with the samples uniformly heated *in vacuo*.

When testing the En 8 and En 19 steels, only the normal thermal conductivity method was used, and for these steels the test sample was in the form of a tube of 1-in. dia. and ⅛-in. wall thickness, initial tests having shown that incomplete hardening would otherwise be obtained for a bar of 1-in. dia. Only one thermal conductivity sample was used for each steel, the original programme being to make measurements for the normalized condition, after O.Q. from 850° C, and after subsequent tempering at 150°, 350°, and 550° C. Further treatments at higher temperatures, including an additional tempering, were, however, introduced and will be detailed later.

Hardness measurements and photomicrographs were made on a separate portion of the tube which was treated at the same time.

RESULTS

In presenting the results of these experiments, the order in which they were made will be adhered to. The results of the main investigation on the high-C, Cr–Mo steel will be first described, then the results for the En 8 and En 19 steels, and finally the results of some additional measurements made on the first-named steel which confirmed that some interesting and what are believed to be new, results obtained after tempering the En 8 and En 19 steels 100° C or so below the transformation region were also obtainable for the high-C, Cr–Mo steel.

(*a*) High-C, Cr–Mo Steel

The results obtained for the thermal conductivity and electrical resistivity of this steel, when tested in the four conditions in which it was supplied, are given in Table III together with values of the Lorenz function, the product of the thermal conductivity and electrical resistivity divided by the absolute temperature.

These results show that the thermal conductivity of this steel when in the hardened state is considerably less than when in the fully tempered state. Over the range 50–100° C the decrease amounts to nearly 40% for the sample which had been O.Q. and tempered at 140° C, and to about 16% for the sample tempered at 350° C. The thermal conductivity of each sample increases with temperature

Table V

THERMAL CONDUCTIVITY (J cm/cm² s ° C), ELECTRICAL RESISTIVITY ($\mu\Omega$ cm²/cm) AND LORENZ FUNCTION (J Ω/s ° C °K) OF En 8 STEEL COMMENCING IN THE NORMALIZED CONDITION

Temperature, ° C	Thermal Conductivity	Electrical Resistivity	Lorenz Function
50	0·45	22·$_5$	3·1$_5$
150	0·44$_5$	29·$_3$	3·1
250	0·43$_5$	37·$_8$	3·1$_5$
350	0·42	47·$_5$	3·2
450	0·39$_5$	58·$_5$	3·2
550	0·37	70·$_5$	3·1$_5$
650	0·33$_5$	85·$_0$	3·1
750	0·29$_5$	100	2·9
850	0·27$_5$	113	2·7$_5$

over this range, but attains a maximum value and subsequently decreases with increase in temperature. The temperature at which the maximum occurs appears to decrease with increase in tempering temperature. For sample 2*a*, however, where the measurements were extended beyond the transformation temperature, a further increase in conductivity occurs when the γ-phase is reached. This positive temperature coefficient is typical of austenitic steels.[5, 6]

The values obtained for the Lorenz function are of interest, as it is on the basis of this quantity that thermal conductivities can be estimated from electrical resistivity measurements. For the conditions studied, the Lorenz functions of the samples tempered at 350° C and higher have comparable values at any particular temperature, but over the range 0–100° C the Lorenz function of the sample tempered at 140° C is about 5% smaller. In the case of the sample heated to high temperatures, the drop in Lorenz function which occurs when the austenitic phase is reached is consistent with earlier results on other steels.[5, 6]

In these earlier papers, attention had been directed to the lower Lorenz function of steels in the γ-phase. X-ray analyses on the present samples indicated that sample 1*a* contained about 14% of retained austenite whereas there was no retained austenite in sample 3*a*. Other deductions made from this analysis were that in 1*a* the martensite had not entirely lost its tetragonal structure, but the change to cubic structure appeared almost complete. In 3*a* there was evidence for the formation of normal carbide having the Fe_3C structure.

(*b*) En 8 Steel

From the bar of En 8 steel which had been supplied in the normalized condition, rods were prepared with diameters of 1, $\frac{1}{4}$, and $\frac{1}{8}$ in. One rod of each size was heated to 850° C and O.Q. The room temperature electrical resistivities obtained for these samples before and after O.Q. are given in Table IV.

It is clear from these results that the larger rods could not be satisfactorily hardened by O.Q. and this led to specimens in the form of tubes of 1 in. external dia. and $\frac{1}{8}$-in. wall-thickness being used to investigate the effect of quenching and tempering on the thermal conductivity. In the first instance, however, thermal conductivity and electrical resistivity determinations were made over the range 50–850° C commencing with the steel in the normalized condition. The results are given in Table V.

Some surface decarburization of the specimen occurred during this test and the final resistivity was 20·2 $\mu\Omega$ cm²/cm, 4·2% lower than initially. A fresh sample was used for the thermal conductivity measurements after O.Q. Before these were undertaken, however, a preliminary study was made of the effect of tempering at various temperatures on the smaller O.Q. rods. The results were exceedingly interesting, and are detailed in Table VI.

The interesting feature was that after tempering at temperatures in the range 550–670° C, both rods had resistivities at room temperature which were considerably lower than the values for the initial

Table VI

EFFECT OF TEMPERING ON ELECTRICAL RESISTIVITY ($\mu\Omega$ cm²/cm) OF O.Q. RODS, En 8 STEEL

For $\frac{1}{8}$-in. dia. Rod			For $\frac{1}{4}$-in. dia. Rod		
Condition	Temp., °C	Electrical Resistivity	Condition	Temp., °C	Electrical Resistivity
Normalized	20	21·3	Normalized	20	21·1
O.Q.	20	26·0	O.Q.	20	25·0$_5$
Tempered, °C:			Tempered, °C:		
140	140	32·5	150	150	33·0
140	20	24·6	150	20	24·2
365	365	49·6	340	340	47·6
365	20	21·7	340	20	22·3
550	550	70·0	530	530	68·4
550	20	19·5	530	20	21·1
670	670	88·0	660	660	87·0
670	20	19·4	660	20	19·7
Heated, °C:			Heated, °C:		
810	810	...	820	820	113·0
810	20	21·1	820	20	20·7

normalized condition. The value increases after treating at 810–820° C. With the test on the $\frac{1}{8}$-in. rod, a vacuum failure at this stage introduced some uncertainty, but the results obtained for the $\frac{1}{4}$-in. rod were free from any such uncertainty and were fully confirmed by the measurements subsequently made with the tubular thermal conductivity specimen.

After the O.Q. thermal conductivity sample of this steel had been tempered for successive periods of 3 h at each of the temperatures of 150°, 350°, and 550° C, the electrical resistivity at 20° C was about 5% less than the corresponding value for the normalized condition. After tempering for a further 3 h at 650° C, the resistivity at 20° C became nearly 12% lower than that for the normalized condition.

Hardness determinations had been made after each tempering treatment, and thermal conductivity measurements were made at each stage over a moderate range of temperature.

Following the tempering at 650° C, the steel was heated for 1 h at 850° and furnace cooled at the rate of 150° C in the first 20 min, and 100° C for the next 40 min. This resulted in a resistivity at 20° C which was close to that of the steel in its initial normalized state.

After reheating to a temperature of 650° C for total periods of 3 to 120 h, the resistivity at 20° C continued to decrease and seemed not to have attained an equilibrium value. The rate of decrease in the resistivity was, however, slower than that when the O.Q. steel had been tempered for 3-h periods at the varying temperatures terminating at 650° C, and the final resistivities obtained after the two treatments at 650° C were of the same order. The hardness, on the other hand, was much lower throughout this second series of treatments.

At this stage, thermal conductivity and electrical resistivity determinations were carried out over the range 50–600° C. The sample was then reheated for 1 h at 850° C and cooled at a much slower rate,

Table VII

THERMAL CONDUCTIVITY (J cm/cm² s ° C), ELECTRICAL RESISTIVITY (μΩ cm²/cm), LORENZ FUNCTION (J Ω/s ° C ° K) AND HARDNESS (D.P.N.) OBTAINED FOR VARIOUS CONDITIONS, En 8 STEEL

Condition	Temperature, ° C	Thermal Conductivity	Electrical Resistivity	$10^8 \times$ Lorenz Function	Hardness
Normalized	20	...	21·1	...	146
O.Q.	20	...	24·4	...	508
	50	0·39$_5$	26·4	3·2	
	100	0·41	29·4	3·2	
Tempered 3 h, 150° C	20	...	23·7	...	503
	50	0·40$_5$	25·7	3·2	
	100	0·41$_5$	28·7	3·2	
Tempered 3 h, 350° C	20	...	21·6	...	429
	50	0·43	23·5	3·1$_5$	
	100	0·43$_5$	26·6	3·1	
	200	0·44	33·7	3·1$_5$	
Tempered 3 h, 550° C	20	...	20·0	...	272
	50	0·48$_5$	21·9	3·3	
	100	0·48$_5$	25·1	3·2$_5$	
	200	0·46$_5$	31·8	3·1$_5$	
Tempered 3 h, 650° C	20	...	18·6	...	211
	50	0·50	20·3	3·1$_5$	
	100	0·50	23·5	3·1$_5$	
	200	0·48$_5$	30·8	3·1$_5$	
'Annealed' 1 h, 850° C	20	...	21·0	...	171
	50	0·48	22·4	3·3	
	100	0·48$_5$	25·5	3·3	
	200	0·48	33·2	3·3$_5$	
Reheated to 650° C for:					
3 h	20	...	19·7	...	159
6 h	20	...	19·5	...	159
30 h	20	...	19·2	...	154
120 h	20	...	18·7	...	143
	50	0·50	20·3	3·1$_5$	
	100	0·50	23·6	3·1$_5$	
	200	0·49	30·8	3·2	
	300	0·47	39·2	3·2	
	400	0·44$_5$	49·4	3·2$_5$	
	500	0·41	61·8	3·2$_5$	
	600	0·37	...	...	
Re-annealed 1 h, 850° C Slower cooling rate	20	...	19·5	...	152

All times are total times at temperatures stated.

from 850° to 700° C in 140 min, and from 700° to 600° C in 215 min.

The complete figures for thermal conductivity, electrical resistivity, derived values of the Lorenz function, and corresponding hardness figures are given in Table VII.

Over the range 50° to 200° C the values of the Lorenz functions for the different conditions are all within the range $3{\cdot}1 \times 10^{-8}$ to $3{\cdot}3 \times 10^{-8}$ J Ω/s ° C ° K, and the changes promoted by the various treatments on the thermal conductivity are seen to parallel those on the electrical conductivity.

It would seem that prolonged heating at 650° C of an annealed sample of this steel leads to thermal and electrical conductivity values which are of the order of 10% greater than those for the steel in the normalized condition. Furthermore, the same improvement in conductivity can be obtained after O.Q. from 850° C and tempering at 650° C for a much shorter time, thereby retaining a certain degree of the hardness due to quenching.

(c) En 19 Steel

Similar tests were undertaken on samples of the En 19 steel, and the results of these are given in Tables VIII and IX.

It will be seen that comparable results were obtained for the two sizes of rod, indicating that for the thermal conductivity investigation a similar tubular specimen could be used.

The room temperature electrical resistivity of such a sample in the annealed state was 24·3 μΩ cm²/cm, compared with 23·1 and 23·5 μΩ cm²/cm, the values given in Table VIII for rods of slightly different composition (*see* Table I). The specimen was then O.Q. from 850° C, after which the room temperature was 32·4 μΩ cm²/cm, an increase of only 33·5% compared with the increase of 49% obtained for the small rods. The microstructural analysis, however, indicated that the tube had been hardened uniformly and was certainly in as fully hardened a condition as could be expected in normal practice.

This received confirmation when some discs of the steel 1-in. dia. and ⅛-in. thick were similarly quenched and gave a hardness of 623 D.P.N. compared with 635 D.P.N. for the tube.

The results given in Table IX were for this tubular specimen.

For the En 19 steel the same general behaviour will be noticed as for En 8. The electrical resistivity at

Table VIII

EFFECT OF O.Q. AND TEMPERING ON THE ELECTRICAL RESISTIVITY (μΩ cm²/cm), En 19 STEEL

For ¼-in. dia. Rod			For ½-in. dia. Rod		
Condition	Temperature, ° C	Electrical Resistivity	Condition	Temperature, ° C	Electrical Resistivity
Fully annealed	20	23·5	Fully annealed	20	23·1
O.Q.	20	35·2	O.Q.	20	34·3
Tempered, ° C:			Tempered, ° C:		
140	140	39·9	150	150	40·7
140	20	32·8	150	20	32·5
365	365	55·8	340	340	53·8
365	20	29·0	340	20	29·7
550	550	74·0	530	530	73·1
550	20	25·5	530	20	27·8
670	670	90·5	660	660	89·0
670	20	23·7	660	20	23·9
			Heated, ° C:		
			820	820	113·0
			820	20	25·0

20° C after tempering at 650° C is lower than after annealing, whereas the hardness is much higher. Further heat-treatment at 650° C after the annealing is again accompanied by a slow decrease in the room-temperature resistivity. It is seen that higher values for the thermal conductivity of this steel are also obtained after heating to 650° C than after any of the other heat treatments studied. Over the temperature range 50–200° C the Lorenz functions for the different conditions now lie within $3{\cdot}1_5 \times 10^{-8}$ to $3{\cdot}4 \times 10^{-8}$ J Ω/s ° C ° K, and there is no systematic change with heat-treatment.

Table IX

VALUES OF THE THERMAL CONDUCTIVITY (J cm/cm² s ° C), ELECTRICAL RESISTIVITY (μΩ cm²/cm), LORENZ FUNCTION (J Ω/s ° C °K) AND HARDNESS (D.P.N.) FOR VARIOUS CONDITIONS, En 19 STEEL

Condition	Temperature, ° C	Thermal Conductivity	Electrical Resistivity	$10^8 \times$ Lorenz Function	Hardness
Annealed	20	...	24·3	...	...
Normalized	20	...	...	...	253 (disc)
O.Q.	20	...	32·8	...	635
	50	$0{\cdot}31_5$	34·0	3·3	
	100	$0{\cdot}32_5$	36·0	$3{\cdot}1_5$	
Tempered 3 h, 150° C	20	...	31·6	...	592
	50	0·33	33·1	3·4	
	100	$0{\cdot}33_5$	36·0	$3{\cdot}2_5$	
Tempered 3 h, 350° C	20	...	28·6	...	492
	50	0·36	30·3	3·4	
	100	0·37	33·2	3·3	
	200	0·37	41·0	3·2	
Tempered 3 h, 550° C	20	...	25·1	...	368
	50	$0{\cdot}38_5$	27·0	3·2	
	100	0·40	30·0	3·2	
	200	0·40	37·0	$3{\cdot}1_5$	
Tempered 3 h, 650° C	20	...	23·0	...	295
	50	0·44	24·9	3·4	
	100	$0{\cdot}45_5$	27·6	$3{\cdot}3_5$	
	200	0·46	34·7	$3{\cdot}3_5$	
'Annealed' 1 h, 850° C	20	...	24·3	...	231
	50	$0{\cdot}42_5$	26·0	3·4	
	100	$0{\cdot}43_5$	29·1	3·4	
	200	$0{\cdot}42_5$	36·2	$3{\cdot}2_5$	
Reheated to 650° C for :					
3 h	20	...	23·3	...	218
6 h	20	...	23·2	...	...
30 h	20	...	22·8	...	214
120 h	20	...	22·3	...	195
	50	0·45	24·2	$3{\cdot}3_5$	
	100	0·45	27·6	$3{\cdot}3_5$	
	200	$0{\cdot}44_5$	34·9	3·3	
	300	$0{\cdot}42_5$	42·8	3·2	
	400	0·40	51·8	3·1	
	500	$0{\cdot}37_5$	63·0	$3{\cdot}0_5$	
	550	$0{\cdot}35_5$	70·0	3·0	
Re-annealed 1 h, 850° C slower cooling rate	20	...	23·4	...	196

All times are total times at temperatures stated.

Table X

EFFECT OF ADDITIONAL TEMPERING ON ELECTRICAL RESISTIVITY (μΩ cm²/cm) AND HARDNESS (D.P.N.), SAMPLE 3a HIGH-C, CR–MO STEEL

Condition	Temperature, ° C	Electrical Resistivity	Hardness
Tempered 350° C for:			
3 h	20	$29{\cdot}_5$	625
20 h	350	$56{\cdot}_3$	
20 h	20	$29{\cdot}_5$	
Tempered 560° C for:			
16 h	560	$75{\cdot}_9$	
16 h	400	56	
16 h	20	$23{\cdot}_7$	403
Tempered 586° C for:			
16 h	586	$79{\cdot}_2$	
Tempered 602° C for:			
3 h	602	$81{\cdot}_5$	
3 h	554	$74{\cdot}_9$	
3 h	20	$22{\cdot}_8$	332
Tempered 655° C for:			
3 h	655	$89{\cdot}_3$	
3 h	20	$23{\cdot}_0$	287
Tempered 700° C for:			
3 h	700	$97{\cdot}_9$	
3 h	20	$23{\cdot}_3$	255
Tempered 750° C for:			
2 h	750	113	
2 h	20	$23{\cdot}_9$	227

X-ray Examination of Steel En 19

Determinations of the retained austenite content of the En 19 steel made by X-ray analysis have shown that about 2% is present after O.Q. Tempering at 150° C does not break down this austenite, but none could be detected in samples tempered at 355° to 650° C. No reflections due to carbide phases were detected in the diffraction patterns of any of the O.Q. or tempered samples.

Microscopic Examination of En 8 and En 19 steels

The microstructures of the En 8 and En 19 steels after O.Q. and each heat-treatment were taken, using the same sample of steel.

The most obvious difference between the behaviour of the two steels would seem to be that En 19 is more resistant to spheroidization of the carbide. Another point of interest is the marked difference in carbide particle size in the 'annealed' En 8 and En 19 steels, after reheating for 120 h at 650° C compared with the quenched and tempered at 650° C material. Presumably these differences are related to the difference in hardness, although the conductivities for the two conditions are comparable.

Additional Measurements on the High-C, Cr–Mo Steel

In view of the interesting results obtained for the

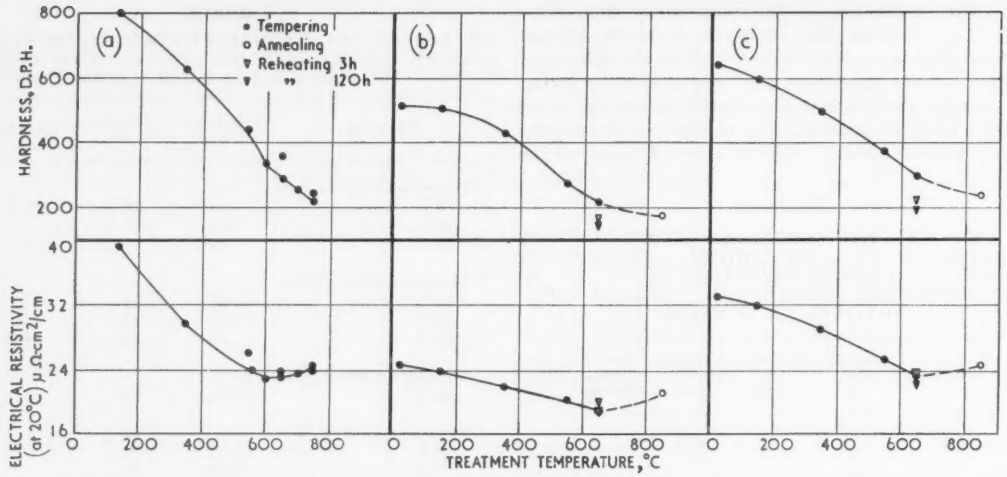


Fig. 1—Variation of hardness and electrical resistivity (at 20° C) of O.Q. steels with tempering, annealing, and reheating

En 8 and En 19 steels after tempering or prolonged heating at 650° C, plotted in Figs. 1 and 2, sections *b* and *c*, some further observations were made on the samples of high-C, Cr–Mo steel first tested.

Sample 1*a*, which had previously been tempered at 140° C, was tempered for an additional period of 3 h at 650° C. Following this treatment, the room temperature resistivity had decreased to 23·4 μΩ cm²/cm and the hardness was 358 D.P.N.

To investigate the matter further, sample 3*a*, the sample that had been tempered at 350° C, was next used. This was fitted with current and potential leads, to allow the resistivity measurements to be made during heating as well as at room temperature. The details and results of this experiment are given in Table X and are reproduced in Figs. 1*a* and 2*a*.

The resistivity values obtained at the limiting high temperature are generally consistent with the original results of Table III. The additional tempering at 350° C brought about no further change in the resistivity. The next heating, however, caused a definite reduction in the resistivity, both at the higher temperature and at room temperature. Whether this was entirely due to the tempering temperature being 10° C higher, or whether it would have occurred with a longer time at 550° C could not be ascertained. It seems probable, however, that sample 4*a* had not been tempered at 550° C long enough for the resistivity to decrease to the final value.

Tempering sample 3*a* at higher temperatures for 3-h periods is seen to result in a minimum value for the resistivity at 20° C following the treatment at about 600° C, whereas the hardness decreases progressively as the tempering temperature increases.

It will be seen that all three steels behave in the same way, the hardness decreasing with increase in tempering temperature, but the room temperature electrical resistivity having a minimum value. For the high-C, Cr–Mo steel, this minimum occurs at about 600° C, which is some 150° C below the transformation temperature of the steel. The curves for the two other steels are shown dotted beyond the 650° C points in Figs. 1*b* and 1*c*, as the location of the minimum has not yet been precisely determined.

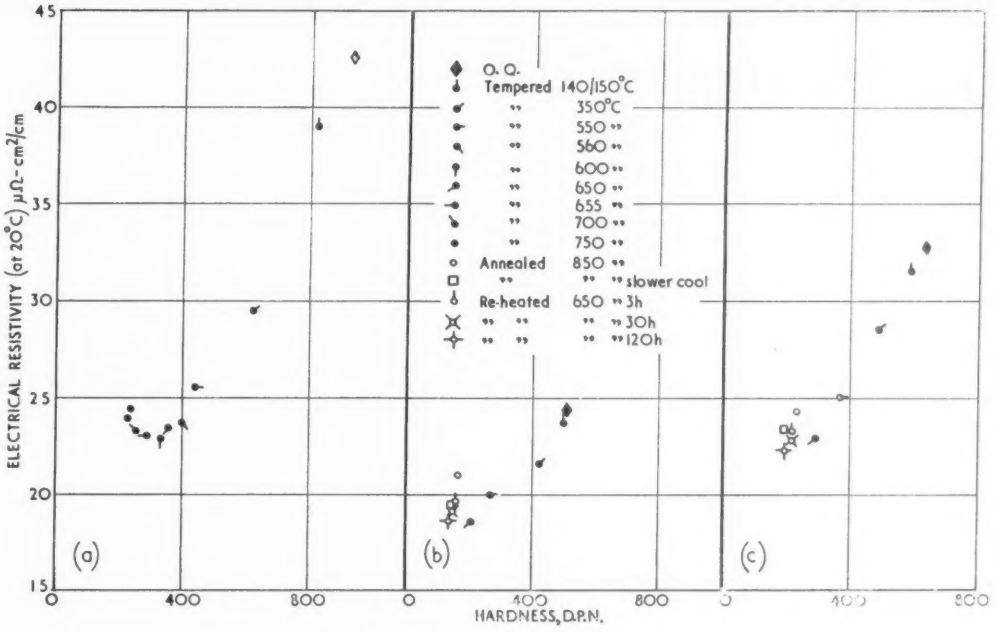
Corresponding thermal conductivity determinations were not made for the high-C, Cr–Mo steel, but assuming the same Lorenz function to apply, the tempering treatment at 600° C can be expected to give a thermal conductivity at 50° C of $0{\cdot}42_5$ J cm²/cm s ° C, a value about 7% greater than that of the sample tempered at 750° C.

An approximate determination of the thermal conductivity of this steel at room temperature for the O.Q. condition has indicated a value of the order of 0·19 J cm/cm² s ° C, which is only about 45% of the maximum value obtainable after tempering at 600° C.

CONCLUSION

The present investigation has shown the same close similarity between the effects of quenching and tempering on the thermal and electrical conductivities of the three steels studied, as was previously found for steel No. 20.[1] It has confirmed the predictions made in the previous paper[1] that the thermal conductivities of some steels may be reduced by a factor of two or more as a result of quenching. This large reduction must lead to the setting up of correspondingly greater temperature differences and thus becomes a contributory factor in promoting conditions suitable for the development of quenching cracks.

The wide range of values that can be obtained for the thermal and electrical conductivities of certain steels after quenching and suitable tempering is also of interest. Of particular interest is the fact that maximum values have been obtained for these properties after tempering below the transformation region in the case of the three steels studied. Whilst



(*a*) High-C, Cr–Mo steel, (*b*) En 8 steel, (*c*) En 19 steel

Fig. 2—Correlation of electrical resistivity at 20° C and hardness of quenched and tempered steels

it is not yet possible to conclude that this will prove to be a general result for all steels, the experimental results so far established are considered likely to be of some practical importance in that they show that this highest conductivity is obtainable before the hardness introduced by the quenching has been entirely removed by subsequent tempering.

Acknowledgments

The authors are indebted to the Thermal Treatment Committee of the British Iron and Steel Research Association for recommending the publication of this work undertaken on their behalf in the Physics Division of the National Physical Laboratory. Particular acknowledgment is made to the interest of the chairman of this Committee, Mr. W. C. Heselwood, of the United Steel Companies, Ltd., and of Dr. F. W. Jones, of the Brown Firth Research Laboratories and Mr. H. Allsop, of Messrs. Brown, Bayley Steels, Ltd., members of this Committee, who both supplied samples of steels used in the investigation. Dr. Jones was also responsible for drawing attention to the need for work in this field and for the hardness figures, and the X-ray analyses made on the steels he had supplied.

Considerable assistance has also been given by the Metallurgy Division of the National Physical Laboratory, notably by Mr. W. J. West who, over an extended period, has been responsible not only for carrying out the series of treatments on the En 8 and En 19 steels, but also for making the hardness determinations on these steels as well as those associated with the additional measurements on the third steel. We are also indebted to Mr. West for taking the photomicrographs.

Mr. W. P. Rees and Mr. B. E. Hopkins have assisted by directing this aspect of the work, commenting on the structural changes, and general discussions.

The X-ray analyses of samples of the En 19 steel were undertaken by the Development and Research Department of the Mond Nickel Co., Ltd., and the authors are indebted to Dr. W. Steven who assisted in this connection.

Mr. G. A. Bainbridge of the Physics Division, National Physical Laboratory, assisted with much of the assembly and observational work.

This paper is published by permission of the Director of the Laboratory.

References

1. R. W. Powell: *J. Iron Steel Inst.*, 1956, vol. 184, pp. 6–10 (this issue).
2. Second Report of Alloy Steels Research Committee, *Iron Steel Inst. Spec. Rep.*, No. 24, pp. 215–251, 1939.
3. *J. Iron Steel Inst.*, 1946, vol. 154, No. 2, pp. 83P–121P.
4. " Physical Constants of Some Commercial Steels at Elevated Temperatures," Ed. British Iron and Steel Research Association: 1953, London, Butterworth.
5. R. W. Powell and M. J. Hickman: *J. Iron Steel Inst.*, 1946, vol. 154, No. 2, pp. 112P–121P.
6. R. W. Powell: *Iron Steel Inst. Spec. Rep.*, No. 43, pp. 315–318, 1952.

The Measurement of Gas Transit Times in a Blast-furnace

By T. W. Johnson

SYNOPSIS

A method of determining quickly the transit time of the blast from a tuyere to various points along the stockline or of making a number of successive measurements at one point is described. A variation of this method to permit continuous sampling at two points simultaneously is outlined. Some experimental results are given proving that the technique is straightforward and satisfactory on a driving blast-furnace. 1274

A METHOD of determining gas transit times in a driving furnace using a radioactive tracer was described by Voice[1] in 1949. This method entailed collecting a series of discrete samples at intervals of 1 s, measuring their activity a few hours later when maximum sensitivity could be obtained, then obtaining a measurement of the transit time by plotting a graph of activity in sample against time of sampling. His results showed that the transit times are of the order of 3 to 10 s. These results indicated the desirability of being able to obtain a continuous record of the radioactivity in the sampling system from the introduction of the radon at the tuyere until it is finally established that all the radioactive gas has been sampled. In addition, such a method should permit successive experiments at very short intervals, enabling a series of results to be obtained within the space of a few minutes, thus eliminating to some degree the effect of short-lived disturbances in the burden. The following paper describes a method which uses an ionization chamber, incorporated in the sampling line, to detect the radioactive tracer as it is sampled, and which to a very large extent attains the objectives outlined above.

INTRODUCTION OF RADON

The radon is introduced into the blast at the tuyere. The method used is that previously described by Voice,[1] the difference being in the attachment of the burster to the tuyere and of its coupling to the detonator ready for firing.

The burster shown in Fig. 1 consists of a steel chamber sealed at one end by a copper bursting disc 0·003 in. in thickness, seated in a recess, and held in position by the male half of a self-sealing Beevic coupling. The screw cap of the explosion chamber carries a modified sparking plug which makes connection between terminals inside and out, the latter pair being connected to a firing unit. The firing unit itself is connected to one of the recorder pens to give a time zero.

To attach the burster to the tuyere, the male end of the coupling is mated to the female half which is permanently attached to the tuyere latch via a water-cooled tube. When no burster is attached the coupling automatically seals off the blast. When a chamber is attached in the firing position, the seal is opened and the explosion compartment is then isolated from the blast by the copper disc only (Fig. 2).

Replacing the exploded charge thus entails breaking an electrical connection, removing the spent chamber with a quick snap action, replacing it by a previously prepared chamber, and remaking the electrical connection, the whole operation taking a few seconds.

Sampling System

The sample is withdrawn through a flexible metal tube, the end of which carries a weighted sintered carborundum filter. This filter has proved very satisfactory in preventing blockages due to the deposition of dust along the tube. To lower the weighted filter to the stockline the fishing rod technique is used.[2] The other end of the tube is connected to a metal spiral immersed in a Drikold-Methanol bath to remove all traces of moisture from the sample. After final cleaning by a simple glass-wool filter the gases pass successively through the detector, a rotometer, and a pump, and discharge to atmosphere at a point remote from the operator.

Detection of Radioactivity

The ionization chamber used as the detector is an integral part of the sampling system. It is essentially a cylinder having gas inlet and outlet ports and with a fine wire at a high potential stretched along its axis. If a radioactive atom emits a particle whilst in the chamber, it initiates a discharge along the wire giving an electrical pulse which, on suitable amplification, can be made to trigger a scaler. Alternatively, if these individual pulses are routed through an integrating circuit, the output of which is recorded, a continuous record of the amount of radioactivity in the chamber is obtained. Thus, if a pulse of radioactive gas passes through the chamber, a record of the variation of activity with time is displayed on the recorder.

The response of the detector and recorder to changes in the amount of radioactivity passing through the detector has been examined in some detail in the laboratory. As the recorder pen is driven by the output of an integrating circuit, the maximum rate at which the pen can return to its zero position is governed by the time constants of that circuit. Hence if the amount of activity in the chamber should suddenly fall to zero, the pen trace would show an exponential

Paper IM/C/55/55 of the Blast Furnace Practice Committee of the Ironmaking Division of the British Iron and Steel Research Association, received on 30th January, 1956. The views expressed are the author's, and are not necessarily endorsed by the Committee as a body.

Mr. Johnson is with the British Iron and Steel Research Association.

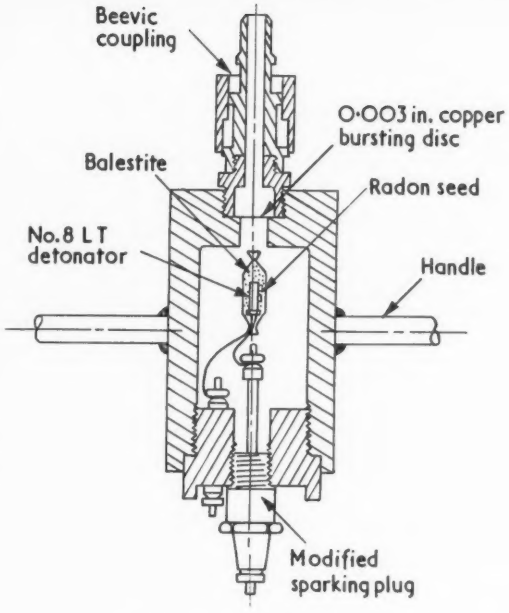
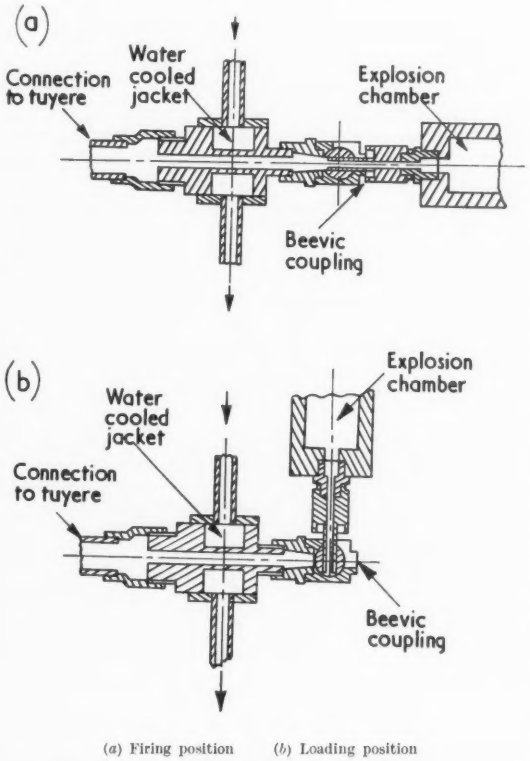


Fig. 1—Radon seed burster



(*a*) Firing position (*b*) Loading position

Fig. 2—Self-sealing coupling

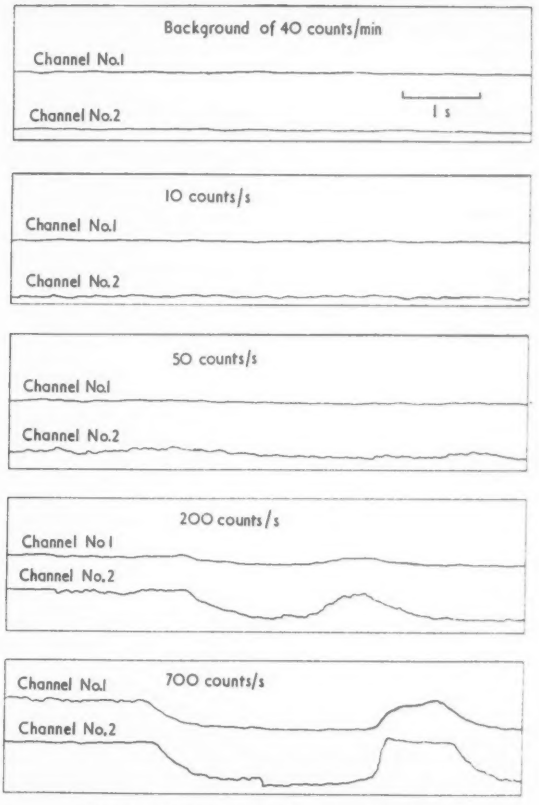


Fig. 3—Traces at various count rates

fall. The time constant, which determines the rate of fall, must be sufficiently large to smooth out the characteristic fluctuations of the radioactive disintegration process but, if it is excessive, the recorder response becomes sluggish, and therefore a compromise value must be chosen.

Traces obtained for various count rates are displayed in Fig. 3, and show that the random fluctuations do not obscure the overall pulse shape. The exponential decay following a sudden drop in activity is clearly illustrated in the last two traces on the figure.

The design of the ionization chamber affects the final recorded shape of a pulse of radioactive gas passing through it, and to study this effect, radon was passed through the detector for varying lengths of time. A valve arrangement was used so that a length of tubing, previously filled with radon mixed with air, could be introduced into the sampling line. The pulse width was varied by altering the length of tubing inserted, and this width could be measured in terms of time from a knowledge of the volume of the tube and the flow rate through it.

Two separate series of experiments were carried out, one with a short length of tube between the valve arrangement and the detector, and the other with the complete sampling system between them. The results of these experiments showed that the recorded electrical pulse is an elongated version of the radioactive pulse, the slope at the ends being slightly decreased.

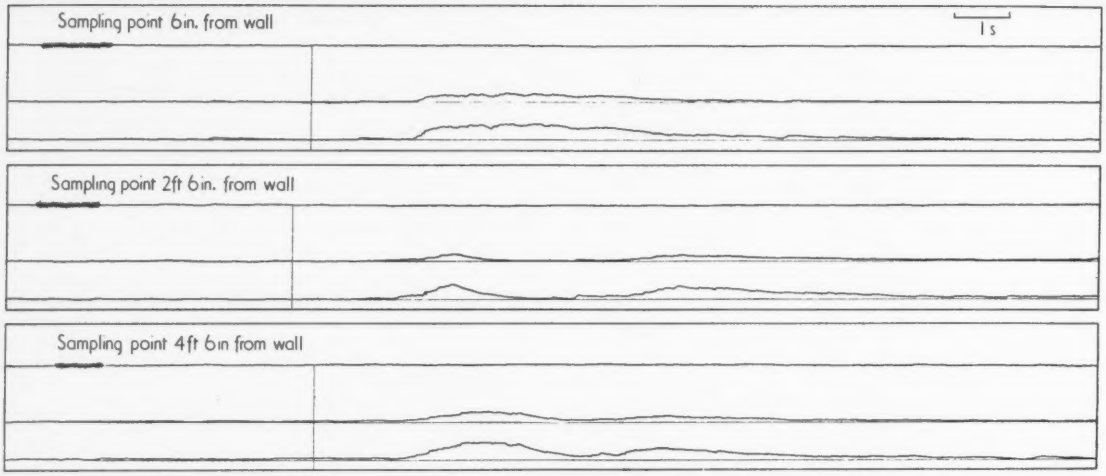


Fig. 4—Traces obtained from radial traverse across a ¼ dia. of stockline

The ratio of the applied pulse width to that recorded approaches unity as the applied width increases, and for pulse durations over 1 s the elongation on recording is very small. Some typical results are given in Table I. The results obtained here are confirmed by the work done by Gregory and Howlett.[3] In practically every experiment completed on blast-furnaces to date, the sampled radon pulses have been considerably longer than 1 s, and therefore the record will be substantially true.

Since the degree of dilution of the tracer as it passes through the burden cannot be calculated, the ratemeter has been constructed with two parallel circuits which give full-scale pen deflections for different maximal counting rates. In this way a record of appropriate sensitivity is always available at the end of the experiment. Full details of the ratemeter circuit are given by Johnson and Meachen.[4]

A Kelvin Hughes high-speed recorder having a chart speed of 2·5 cm/s has been used throughout all this work.

EXPERIMENTAL TECHNIQUE

The detector, cooling coils, rotameter, and pump are normally set up on the charging platform of the furnace and connected by rubber tubing to the flexible metal tubing on the ' fishing rod ' platform a few feet below. The firing box is connected to a long twin flex which is lowered down the side of the furnace to the tuyere to which the bursters are to be attached.

Immediately before a set of experiments, blast-furnace gas is drawn through the sampling system and the working voltage of the ionization chamber, which is dependent on gas composition and pressure, is determined. The sampling tube is then lowered to the appropriate point on the stockline, the recorder started and the charge fired. After all the radioactivity has been sampled the recorder is switched off and the spent chamber replaced ready for the next experiment.

The co-ordination of these activities carried on at three different levels on the furnace has, in the past, presented some difficulties but these have been completely overcome by the use of an intercommunication system. Each operator wears a throat microphone and a pair of earphones fed through a common amplifier. In this way normal conversation is possible even though the probe manipulators wear gas masks.

RESULTS

Some recorder traces obtained during a series of experiments are shown in Fig. 4. Of particular interest are the double pulses recorded on the last two traces, and to a lesser degree, on the first. These are believed to be significant but the reasons for them are not known. During these experiments six runs in all were completed in two sets of three. For the first set, sampling was done at one point only with a view to assessing the time required to prepare for a run after the completion of its predecessor. This time was shown to be of the order 20 to 30 s. In the second set a radial traverse of the furnace was done taking samples at 6 in., 2 ft 6 in., and 4 ft 6 in. from the inwall. This traverse was completed in 3 min.

Table I

TYPICAL EXPERIMENTAL RESULTS

Calculated width of radioactive input pulse, s	Measured width of recorded pulse, s	
	(i) Reversing valve immediately before detector	(ii) Reversing valve at end of sampling system
0·16	0·22	0·69
0·42	0·49	0·92
1·07	1·17	1·41
2·13	2·17	2·24

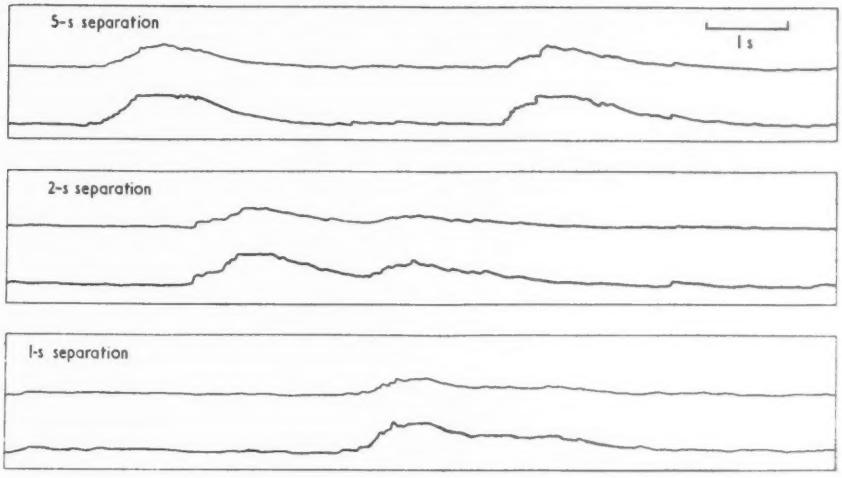


Fig. 5—Simultaneous sampling: Effect of varying time delay in one line, input pulses 0·75 s long

The signal from the firing box appears as a sine wave on the trace, the beginning of the wave being the actual moment of firing. The time taken for the sample to travel along the sampling system is calculated from a measurement of the volume of the system and the sampling rate. In Fig. 4 this calculated time is measured from the zero time and a black line drawn across the trace. Actual transit times through the burden are measured from this line. The transit times for the three traces shown in Fig. 4 are tabulated in Table II ; these are of the same order as those obtained by Voice. The traces also confirm the previous results which show in many cases a long-drawn-out pulse of radioactivity at the sampling point.

Generally, the equipment has proved satisfactory but it has been found difficult on occasions to maintain the amplifiers under the adverse conditions encountered on a blast-furnace. Recent developments in the field of scintillation detectors indicate that a scintillation flow counter could be adapted to replace the ionization chamber: this would allow more robust equipment to be used and would eliminate the necessity of determining working voltages to suit local conditions since such detectors, unlike the ionization chamber, are independent of the relatively small fluctuations in gas pressure and composition encountered in blast-furnace exploration. Work along these lines is proceeding.

Table II
TRANSIT TIMES FOR TRACES

Distance of sampling point from wall	Transit times, s			
	First pulse of radioactive tracer		Second pulse of radioactive tracer	
	Time to leading edge	Time to maximum activity	Time to leading edge	Time to maximum activity
6 in.	2·1	3·2	5·1 (doubtful)	5·4
2 ft 6 in.	1·7	3·0	5·1	7·0
4 ft 6 in.	1·6	2·8	5·1	6·3

Simultaneous Sampling at Two Points

A method of sampling simultaneously from two points has also been developed. In this, two similar sampling systems are joined together at the inlet port to the ionizing chamber. Samples from two different points travel along their separate systems and then pass through the detector where their activity is measured and recorded. One system is longer than the other by a known amount, and thus pulses arriving at the sampling points at the same time are separated on the recorder trace by a distance equivalent to the extra transit time in the longer system. This enables each pulse to be shown separately on the trace and thus avoids any difficulty in interpretation which would occur if, when using identical lengths, the radioactive tracer arrived at the two sampling points more or less together. The effect of varying the extra length for radioactive pulses of the same width sampled together, is shown in Fig. 5.

Two samples having different transit times in the burden will be separated on the recorder trace by a distance equal to the algebraic sum of the difference in the actual transit times in the burden and the difference in the sampling systems. The results of two previously determined separate transit times are desirable if this method is used in order that the sampling lines may be adjusted to make the two differences additive, and thus ensure clear definition of both pulses.

The speed with which successive runs can be done with the single sampling system has made the simultaneous sampling, with its increased manipulative difficulties, much less attractive, and in addition the long pulses recorded in the work to date would necessitate an abnormally long time delay in one line. For

these reasons the simultaneous sampling method has not been applied to the blast-furnace but it should be an extremely accurate way of obtaining residence times of gases, e.g. in complicated lengths of ducting, where normal methods cannot be applied.

CONCLUSIONS

A method has been developed which enables the transit times of the blast through a blast-furnace burden, from a tuyere to various points along a radius on the stockline, to be measured within the space of a few minutes ; or to repeat measurements at a given sampling point within 30 s of each other. The shape of the radioactive pulse as it is sampled on the stockline is displayed on a recorder trace. A variation of this method makes it possible to determine the residence times of gases in systems, provided that the sampled pulses are relatively well defined.

The technique is straightforward and has proved satisfactory on a driving furnace. The troubles experienced with the electronic equipment associated with the ionization chamber detector should be eradicated as modern techniques improve the design and manufacture of this type of equipment or, alternatively, if the ionization chamber is replaced by the more robust scintillation detector.

The method has been used to measure transit times but it is not necessarily limited to this one application, and can be adapted to obtain additional information on the history of the blast during its passage through the stack.

Acknowledgments

The author wishes to acknowledge the work of Mr. D. Meachen who played an important part in the development stages of this work. He also wishes to thank his colleagues on the Field Trials team of the Iron Making Division for their assistance on site and the Management of Messrs. Dorman Long (Steel) Ltd., for permitting furnace trials on their plant to be carried out whenever necessary.

References

1. E. W. VOICE: *J. Iron Steel Inst.*, 1949, vol. 163, pp. 312–315.
2. E. W. VOICE: *Ibid.*, 1949, vol. 162, pp. 450–451.
3. J. N. GREGORY and J. HOWLETT, Report No. AERE C/R 490, December, 1950.
4. T. W. JOHNSON and D. MEACHEN: *Research*, 1954, vol. 7, pp. 356–359.

Correspondence on the Paper—

The Straining of Metals by Indentation including Work-Softening Effects*

By G. H. WILLIAMS and H. O'NEILL

Dr. **D. S. Dugdale** (M.E.R.L., East Kilbride) wrote: It is often supposed that indentation hardness can be adequately discussed by assuming that engineering materials behave in approximately the same way as the ideal plastic-rigid material on which a good deal of theoretical work has been based. This paper is thought to be of the greatest value in that it draws attention to the limited utility of this assumption. For a plastic-rigid material, all the displaced material must appear in a lip raised above the original surface. Yet the diagrams clearly show that for the metals used it is usual for the displaced material to be pushed downwards into the specimen, giving deformation and hardening over an extensive region beneath the impression. As deformation of this kind is quite incompatible with the deformation of the idealized material, it is a little surprising that experimental results are compared with Ischlinski's theoretical result without further comment.

A convenient method[1] of investigating the shape of the deformed region is to section the impression and then etch the surface. In Figs. *A* (i) and (ii) patterns are shown for Brinell impressions made in annealed mild steel. The surfaces were etched for several hours with Fry's reagent, and were then lightly polished. It appears that the most severely deformed material adjacent to the indenter was not attacked by the reagent. The outer boundary of the region in which yielding occurred seems to consist of two parts. Near the surface the shape of the boundary suggests flow to the free surface after the fashion of the theoretical flow

J. Iron Steel Inst., 1956, vol. 182, March, pp. 266–273.

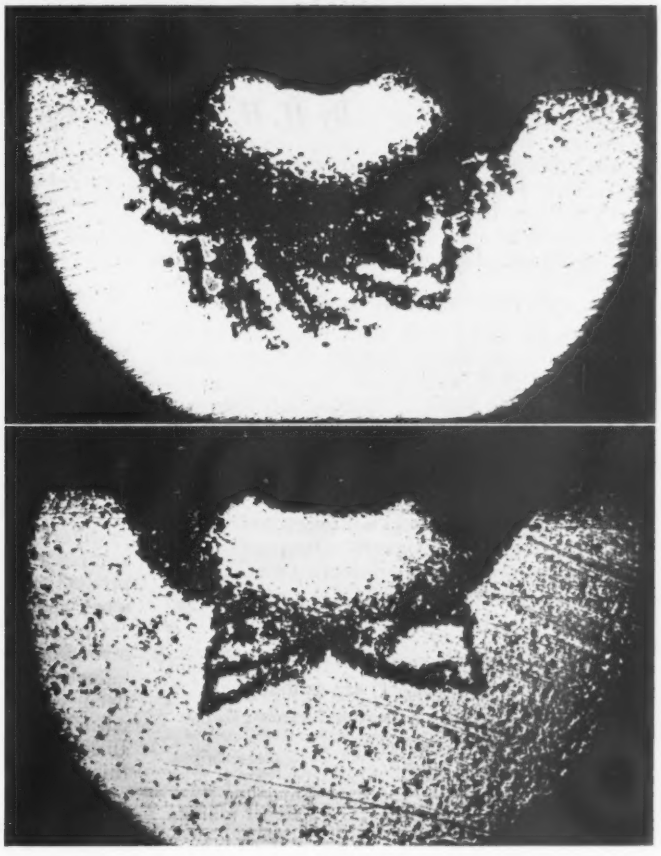


Fig. A—Etched sections of Brinell impressions

for a plastic-rigid material. Beneath the impression, the strain figures are reminiscent of the spiral slip-lines for the plastic expansion of a thick cylinder subjected to internal pressure. They suggest accommodation of the displaced volume by subsidence of material into the interior of the specimen.

The roughly semi-circular shape of the hardness contours shown by the authors seems to favour the writer's proposal[2] that indentation hardness can be quite logically examined in relation to the pressure required to expand a cavity in an infinite block of material. Exceptionally, Fig. 5 indicates a fairly localized field of flow, which seems to agree with the conclusion[2] that for an indenter of vertex angle 60°, the deformation of annealed copper was substantially of the ' plastic-rigid ' type.

AUTHORS' REPLY

Dr. **G. H. Williams** and Professor **Hugh O'Neill** wrote in reply: We appreciate the point raised by Dr. Dugdale regarding the theoretical deductions of Ischlinski. We have not commented on this aspect of the work which has received attention by investigators such as Hill and Tabor. The former considers that Ischlinski's use of the Haar–Karman hypothesis is without physical reality for metals and introduces an error of unknown magnitude, whilst the latter states that " the type of error involved does not appear to be serious." We have simply noted the value of the elastic-hardness/yield-stress ratio for copper.

Figures *A* (i) and (ii) obtained by the etching of sectioned identations in steel with Fry's reagent correspond with similar structures published for instance by Fell[3] in 1927. It is agreed that the spiral slip lines remind one of the plastic expansion of a thick cylinder subjected to internal fluid pressure, and this was the analogy for ball indentation put forward by Professor B. P. Haigh in 1920.

We are grateful to Dr. Dugdale for drawing our attention to his own work on pyramidal indenters, which was published after our paper was written. Comparison of the hardness contours for the conical indentations in Figs. 3, 4, and 5 shows that as the indenter cone angle decreases, the depth of the work-hardened zone decreases, and spreads outwards along the surface of the metal. We agree that Fig. 5 for the 60° cone shows an exceptional hardness distribution with a minimum depth below the vertex of the indenter, and the deformation is more of the ' plastic-rigid ' type.

REFERENCES

1. B. B. Hundy: *Metallurgia*, 1954, vol. 49, pp. 108–118.
2. D. S. Dugdale: *J. Mech. Phys. Solids*, 1955, vol. 3, pp. 206–211.
3. E. W. Fell: *Iron Steel Inst., Carn Schol. Mem.*, 1927, vol. 16, pp. 101–123.

Maximum Utilization and Problems of Wide-strip Rolling and Sheet Finishing Equipment

By H. H. Ascough, M.I.Mech.E.

SYNOPSIS

The paper describes the system of operating the 45-in. Slabbing Mill and 80-in. Hot and Cold Strip Mills of The Steel Company of Wales, and includes detailed operating data. Significant factors influencing productivity are commented upon in relation to the future design of similar installations. 1155

THE BACKGROUND to this paper is the slabbing and 80-in. strip mills at the Abbey Works of the Steel Company of Wales Ltd.,[1] from which the final products are hot- and cold-rolled sheet, hot-rolled strip for cold-rolling into tinplate, and black sheets and plates.

CUSTOMERS AND ORDERS

Without a full order book there could not be full rolling programmes, and it follows that customers' requirements both in quality and quantity must be the foundation upon which to establish any successful enterprise. However, mass production feeds on standardization, and this is particularly true of continuous rolling mills; without large tonnages of similar width and gauge for the manufacture of cans, tubes, or motor cars, strip mills could not operate efficiently. This fact is recognized by many other users of flat rolled products and their manufacturing methods and orders are adjusted accordingly.

PLANNING

The processes which convert ingots into cold-rolled sheets and into tinplate (Fig. 1) are as follows:

Soaking pit : Slabbing mill : Reheating furnace : Hot strip mill : Continuous pickle line

Cold-rolling		Cold-rolling
Cleaning		
Annealing		Annealing
Temper rolling		Temper rolling
Tinning / Shearing	= Reversed if no continuous tinning line	Shearing

The grouping and scheduling of orders is the basis of efficient rolling, and for this purpose, and also to progress the order from the time the sales department has released it for rolling, an efficient planning department is essential. This department is in sections, each of which controls its respective processes in the mill. An important member is the figuring section, which computes the orders from numbers of sheets, etc., into cold-rolled coils, slabs, and finally ingots. The yield and average conversion factors adopted in their calculations vitally affect the economic results of the mills, and it is therefore of supreme importance that these figures should be a realistic anticipation of consistently low rejects and high yields. The metallurgical routing office is closely related to this department; its function is to scrutinize each order and nominate the ideal analysis and sequence of processing to meet the duty ultimately required from the sheet. This selection is made from a choice of over one hundred combinations of grades and processes embracing such special qualities as silicon- and corrosion-resisting steels.

Identification is of paramount importance and throughout the Abbey Mills this is achieved with the aid of ingot, slab (Fig. 2), and lift cards, which trail the product through the sequence of processes via lamson tubes. Figures 3*a–c* show diagrammatically the flow of information and sequence of operation through the plant. In order to utilize each piece of equipment to the maximum advantage it is necessary to have daily a detailed stock sheet available to all concerned, particularly because stocks ahead of high production units tend to build up rapidly during a short cessation of production, and immediate action has to be taken to divert material destined for a congested unit into a more receptive channel. Conversely, a spurt of production by a unit might quickly 'dry up' the stock ahead and bring itself to a standstill.

One of the most difficult problems in planning the layout of high-production rolling mills, comprising a sequence of many different units, is to maintain a balance of outputs between them, i.e. if the potential output per week of the 3-stand cold-reduction mill is 15,000 tons and the output of a pickle line serving this mill is 20,000 tons, there is a utilization loss of pickle-line output of 5000 tons.

SOAKING PITS

Feeding the slabbing mill with perfectly soaked hot steel requires careful planning from the movement of hot-ingot trains, stripping, charging, and drawing, to the transportation to the mill for weighing and turning before rolling.

Figure 4 shows the graphical method of planning the drawing and charging of twenty Amsler-Morton soaking pits. Colours are used to distinguish the occupancy of the pit and the track time is superimposed in each rectangle, the length of which determines the total length of time the ingots are in the pit (which is governed by Table I). Planning must consider crane deployment over pits simultaneously

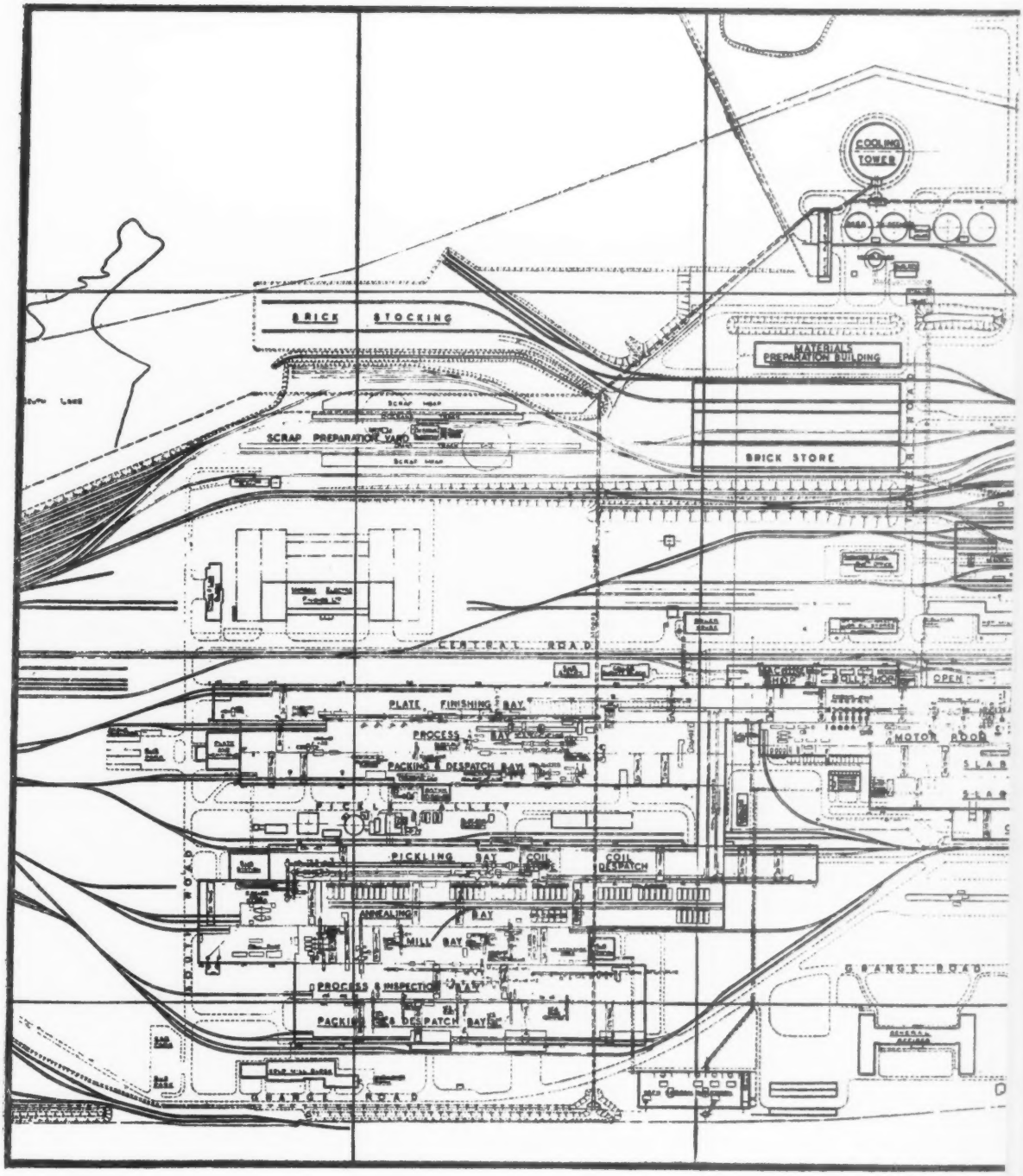
Table I—SOAKING PITS

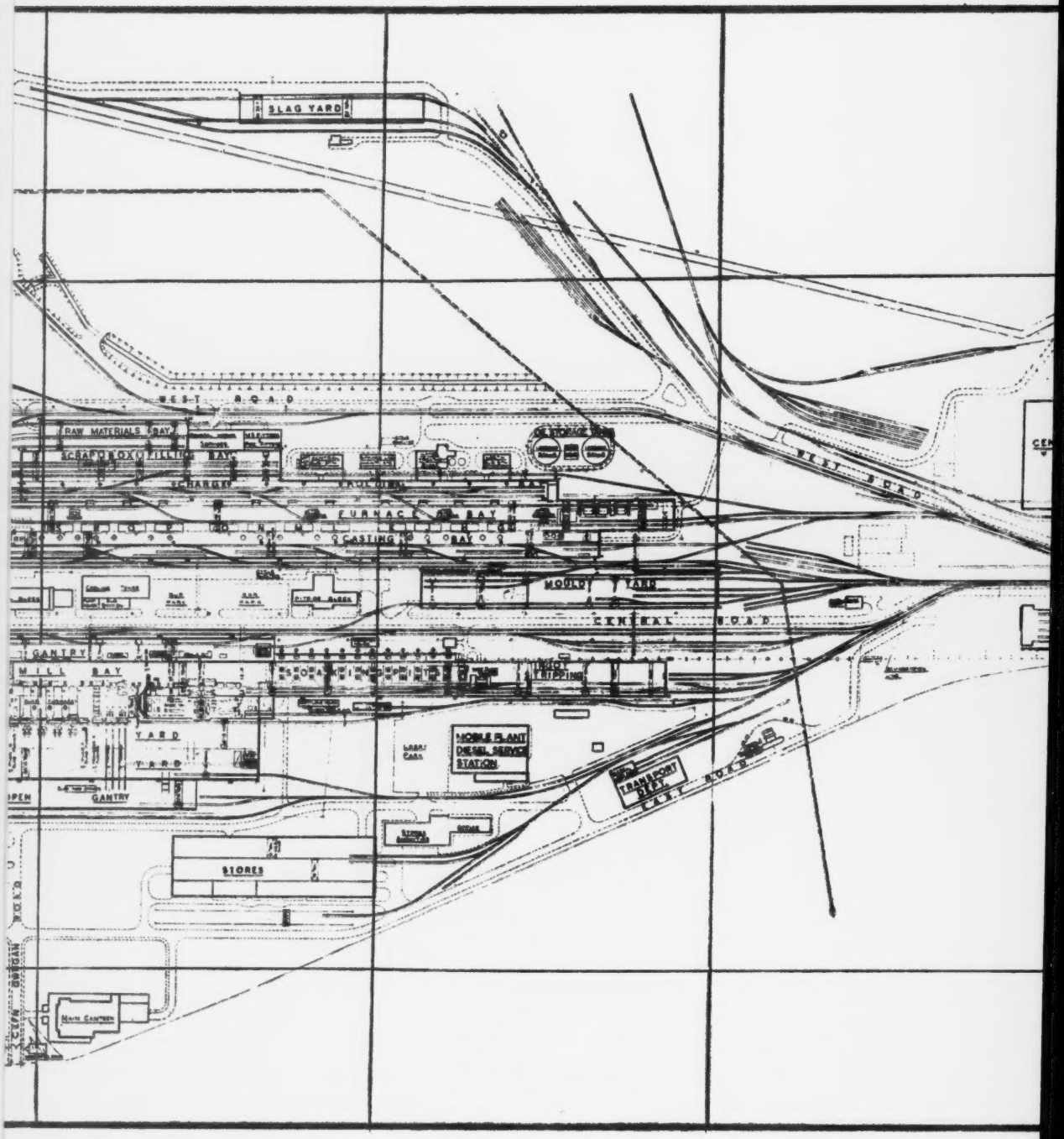
(10, 12, and 15-ton ingots)

Track Time: Commence–Teem–Finish–Charge		Time to Reach Temperature		Soaking Period		Total Heating Time	
h	min	h	min	h	min	h	min
2	0		30	1	30	2	0
2	30		45	2	0	2	45
3	0	1	0	2	30	3	30
3	30	2	0	3	0	5	0
4	0	2	0	4	0	6	0
4	30	2	30	4	0	6	30
5	0	3	0	4	0	7	0
Cold		2–10 h		5	0	13–15 h	

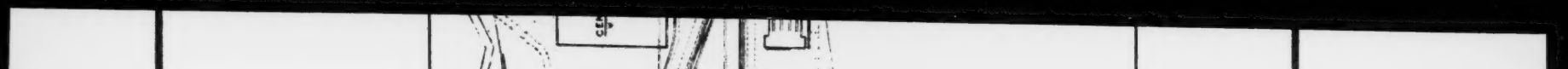
A paper presented to the Swansea and District Metallurgical Society on 26th March, 1955.

Mr. Ascough is Rolling Mills Superintendent at the Abbey Works of the Steel Company of Wales Ltd.


COOLING TOWER
BRICK STOCKING
MATERIALS PREPARATION BUILDING
SCRAP PREPARATION YARD
BRICK STORE
CENTRAL ROAD
PLATE FINISHING BAY
PROCESS BAY
PACKING & DESPATCH BAY
MOTOR ROOM
PICKLING BAY
COIL
COIL DESPATCH
ANNEALING BAY
MILL BAY
PROCESS & INSPECTION BAY
PACKING & DESPATCH BAY
SOUTH ROAD
GRANGE ROAD
GRANGE ROAD



ig. 1—General plan of Abbey Works



SHOP

drawing and charging, and also the selection of pits nearest to the mill for ingots having the highest rolling rates. Conservation of heat by means of short track times is of particular significance to the throughput of a soaking pit. A high rolling rate also permits quick discharge of a pit, and therefore increases utilization and reduces the time ingots are waiting for pit accommodation. This provides some relief to the soaking-pit problem caused by steel-furnace bunching. One of the most aggravating problems governing the efficiency of combustion is the lack of precision in the air/gas ratio with automatic controls over the full range of gas flow. At Abbey a compromise has been struck by having two settings.

The number of pits required for a given slabbing mill throughput is usually a compromise between the total required to heat cold steel stocked during idle mill shifts and normal supply from the O.H. shop. It has been found that with an average track time of 2 h 20 min, no cold ingots, a calorific value of fuel of 135 B.t.u./ft^3, an average ingot weight of 14 tons, and a pit capacity of 95 tons, 14 pits can heat at the rate of 34,000 tons of ingots per week, with an overall fuel consumption of 750,000 B.t.u./ton.

The controversial subject of dry versus wet bottoms[2] will not be debated here, although at Abbey many advantages have been derived from breeze bottoms. With good automatic control of combustion very little, if any, slag is made. Nevertheless, instruments can be in error, and slag through a burner block of a bottom-fired pit or through a recuperator of the Amsler-Morton pit design is disastrous. In the author's opinion, the disadvantages of changing the coke breeze every 5–6 days through trap-doors in the bottom of the pit are outweighed by the extension to the life of the refractories and the structure of the pit which this practice affords. A survey of all modern pits throughout the world, giving fuel costs, maintenance costs, throughput, etc., would be very useful in selecting the most economical design and practice.[3]

Soaking-pit throughput is related in some measure to prompt stripping, charging, and drawing of ingots, and three ingot-charging cranes, together with three stripping cranes, are necessary for steel outputs of over 40,000 tons per week. This provides a comfortable margin for maintenance if the maintenance period is selected at the time of minimum flow of ingots from the steelplants.

Transporting the ingot after drawing from the soaking pit to the mill presents little difficulty up to outputs of 45,000 tons per week, using a single buggy of the orthodox type running alongside pits in pairs. However, as this layout only permits additional soaking pits to be installed further from the

Table II

SUMMARIZED MILL DATA SHEET

Abbey hot mills

2-High or 4-High	Mill Stand	Length of Work Roll Body, in.	Nominal Dia. of Rolls, in.		Distance from Preceding Stand	Motor Data				Roll Speed			Strip Speed, ft/min			Screwdown Motors			
			Work	Back-up		h.p.	Type	Minimum rev/min	Maximum rev/min	Gear Ratio	Minimum rev/min	Maximum rev/min	Min.	Max.	No.	h.p.	volts	rev/min	Type
2	Slabbing	115	45	...	...	2 4600	d.c., Ward-Leonard	0–40	80	Direct	0–40	80	...	...	2	200	0–500	0–820	d.c., W.L.
...	Vertical edging	11	40	...	94 ft. 8½ in.	800	Synch.	...	375	11.18.1	...	33·54	...	352	2	25	440	650	d.c.
2	Roughing scale breaker	72	36	...	...	1250	Induction	...	375	16.982.1	...	22·1	...	209	...	25	440	700–1500	d.c.
4	No. 1 broadside	130	42	54	30 ft. 0 in.	3500	Slip-ring	...	500	25.875.1	...	19·32	...	210	2	50	440	570–1450	d.c.
4	No. 2 roughер	80	36	54	51 ft. 4½ in.	4500	Synch.	...	500	21.14.1	...	23·65	...	223	2	75	440	575–1350	d.c.
4	No. 3 roughер	80	36	54	60 ft. 0 in.	4500	Synch.	...	500	14.966.1	...	33·4	...	314	2	75	440	525–1350	d.c.
4	No. 4 roughер	80	27	54	96 ft. 0 in.	4500	Synch.	...	500	8.214.1	...	60·86	...	430	2	75	440	525–1350	d.c.
4	No. 5 finisher	80	27	54	186 ft. 0 in.	4500	d.c.	125	282	4.657.1	26·83	60·54	190	428	2	75	440	525–1350	d.c.
4	No. 6 ,,	80	27	54	19 ft. 0 in.	4500	d.c.	125	245	2.605.1	47·97	94·4	339	668	2	75	440	525–1350	d.c.
4	No. 7 ,,	80	27	54	19 ft. 0 in.	5000	d.c.	78	156	Direct	78	156	552	1102	2	75	440	525–1350	d.c.
4	No. 8 ,,	80	27	54	19 ft. 0 in.	5000	d.c.	105	210	Direct	105	210	742	1485	2	75	440	525–1350	d.c.
4	No. 9 ,,	80	27	54	19 ft. 0 in.	5000	d.c.	125	250	Direct	125	250	884	1768	2	75	440	525–1350	d.c.
4	No. 10 ,,	80	27	54	19 ft. 0 in.	4000	d.c.	132	296	Direct	132	296	932	2095	2	50	440	525–1350	d.c.
Coiler	Mandrell Pinch roll	30 Top 36 Bot. 16				0 300 0 75	d.c., Ward-Leonard	0,300/900		2.46.1 Top: 2.25.1 Bot.: direct									

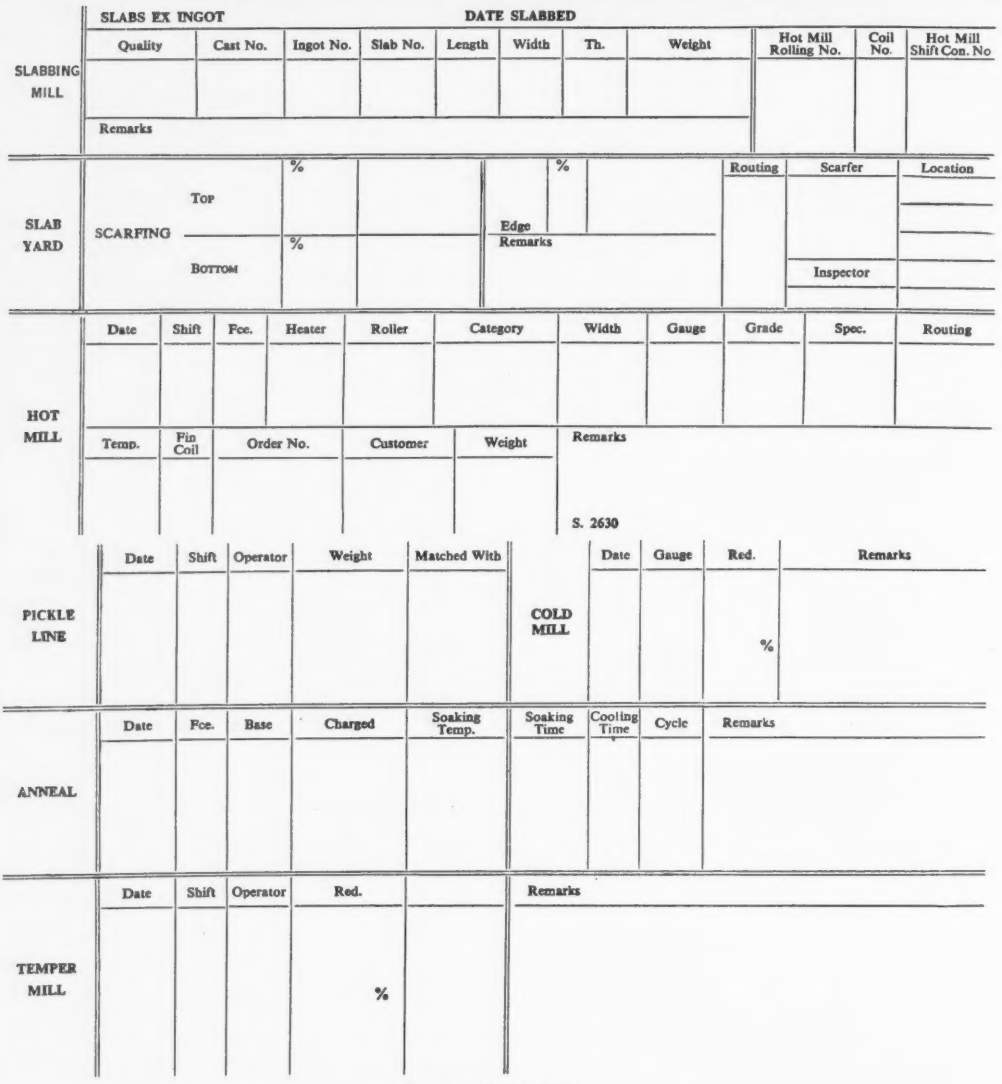


Fig. 2—Slab card

rolls, the single-buggy service becomes increasingly critical and finally cannot meet the demands of the highest rolling rates. The problem of charging, drawing, and buggy service tends to produce a layout which permits charging from one side of the soaking pits and drawing to the opposite side with two buggies feeding the mill. Thus, assuming a universal slabbing mill rolling 75,000 tons of ingots per week, the ideal layout might be:

(i) Soaking pits on either side of two central buggy tracks, ingot car tracks on the opposite side, or
(ii) Soaking pits laid out at right-angles to the mill with two buggies drawing from left and right.

Alternative aid to the single-buggy service can be introduced either by extending the mill receiving table some distance along the soaking pits or by using a shuttle car between the buggy and the mill.

SLABBING MILL (TABLE II)

Although presentation of the ingot bottom first to the mill has advantages in yield and reduces the risk of lamination breaking in the strip mill, this practice sometimes results in idle passes when these fins are on the ingot. It is imperative, therefore, that ingots are free from fins and loose tops.

The 45-in. dia. rolls and power of the Abbey slabbing mill are of the largest type in use. The profile of the rolls provides a 14-in. edging pass, a 71-in. bull head, and a 9½-in. and a 6-in. edging pass. The maximum lift between barrels is 68 in. Speed range is 40–80 rev/min. Screw speed is approximately 7 in./s. Reversal of the 27,000-h.p. motors (490 m-ton) can be accomplished in 1·8 s. Allowing reasonable edge work, the maximum width of slab obtainable is 62 in. The minimum width of slab required is 27 in. and thickness ranges from 5 to 8½ in.

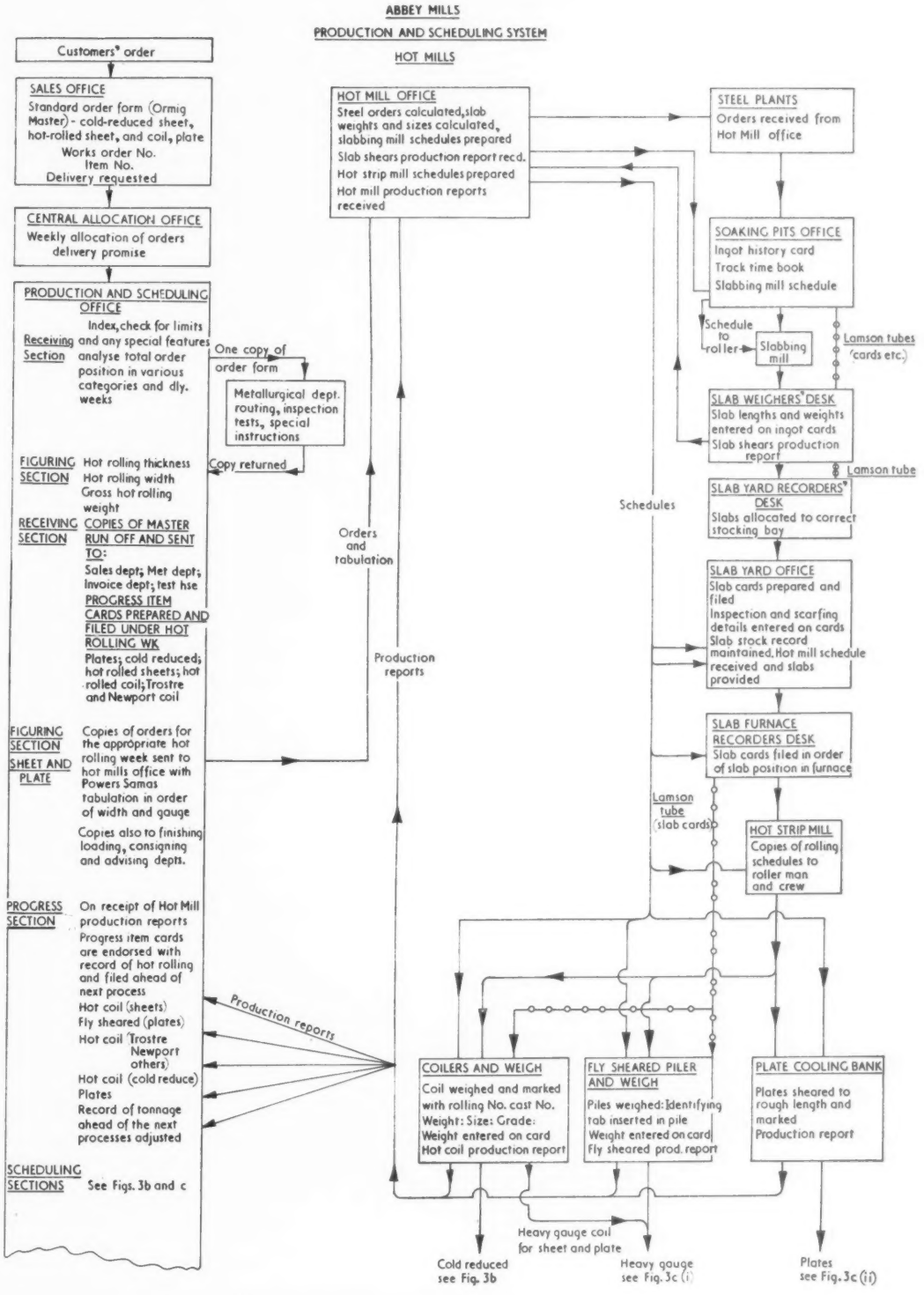

ABBEY MILLS
PRODUCTION AND SCHEDULING SYSTEM
HOT MILLS
Customers' order
SALES OFFICE
Standard order form (Ormig Master) - cold-reduced sheet, hot-rolled sheet, and coil, plate
Works order No.
Item No.
Delivery requested
CENTRAL ALLOCATION OFFICE
Weekly allocation of orders delivery promise
PRODUCTION AND SCHEDULING OFFICE
Receiving Section
Index, check for limits and any special features
analyse total order position in various categories and dly. weeks
One copy of order form
Metallurgical dept. routing, inspection tests, special instructions
Copy returned
FIGURING SECTION
Hot rolling thickness
Hot rolling width
Gross hot rolling weight
RECEIVING SECTION
COPIES OF MASTER RUN OFF AND SENT TO:
Sales dept; Met dept; Invoice dept; test hse
PROGRESS ITEM CARDS PREPARED AND FILED UNDER HOT ROLLING WK
Plates; cold reduced; hot rolled sheets; hot rolled coil; Trostre and Newport coil
FIGURING SECTION SHEET AND PLATE
Copies of orders for the appropriate hot rolling week sent to hot mills office with Powers Samas tabulation in order of width and gauge
Copies also to finishing, loading, consigning and advising depts.
PROGRESS SECTION
On receipt of Hot Mill production reports
Progress item cards are endorsed with record of hot rolling and filed ahead of next process
Hot coil (sheets)
Fly sheared (plates)
Hot coil (Trostre Newport others)
Hot coil (cold reduce)
Plates
Record of tonnage ahead of the next processes adjusted
SCHEDULING SECTIONS
See Figs. 3b and c
HOT MILL OFFICE
Steel orders calculated, slab weights and sizes calculated, slabbing mill schedules prepared
Slab shears production report recd.
Hot strip mill schedules prepared
Hot mill production reports received
Orders and tabulation
Production reports
STEEL PLANTS
Orders received from Hot Mill office
SOAKING PITS OFFICE
Ingot history card
Track time book
Slabbing mill schedule
Schedule to roller
Slabbing mill
Lamson tubes (cards etc.)
SLAB WEIGHERS' DESK
Slab lengths and weights entered on ingot cards
Slab shears production report
Lamson tube
Schedules
SLAB YARD RECORDERS' DESK
Slabs allocated to correct stocking bay
SLAB YARD OFFICE
Slab cards prepared and filed
Inspection and scarfing details entered on cards
Slab stock record maintained. Hot mill schedule received and slabs provided
SLAB FURNACE RECORDERS DESK
Slab cards filed in order of slab position in furnace
Lamson tube (slab cards)
HOT STRIP MILL
Copies of rolling schedules to roller man and crew
Production reports
COILERS AND WEIGH
Coil weighed and marked with rolling No. cast No. Weight: Size: Grade:
Weight entered on card
Hot coil production report
FLY SHEARED PILER AND WEIGH
Piles weighed: Identifying tab inserted in pile
Weight entered on card
Fly sheared prod. report
PLATE COOLING BANK
Plates sheared to rough length and marked
Production report
Heavy gauge coil for sheet and plate
Cold reduced see Fig. 3b
Heavy gauge see Fig. 3c (i)
Plates see Fig. 3c (ii)

Fig. 3*a*—Flow of information: hot mills

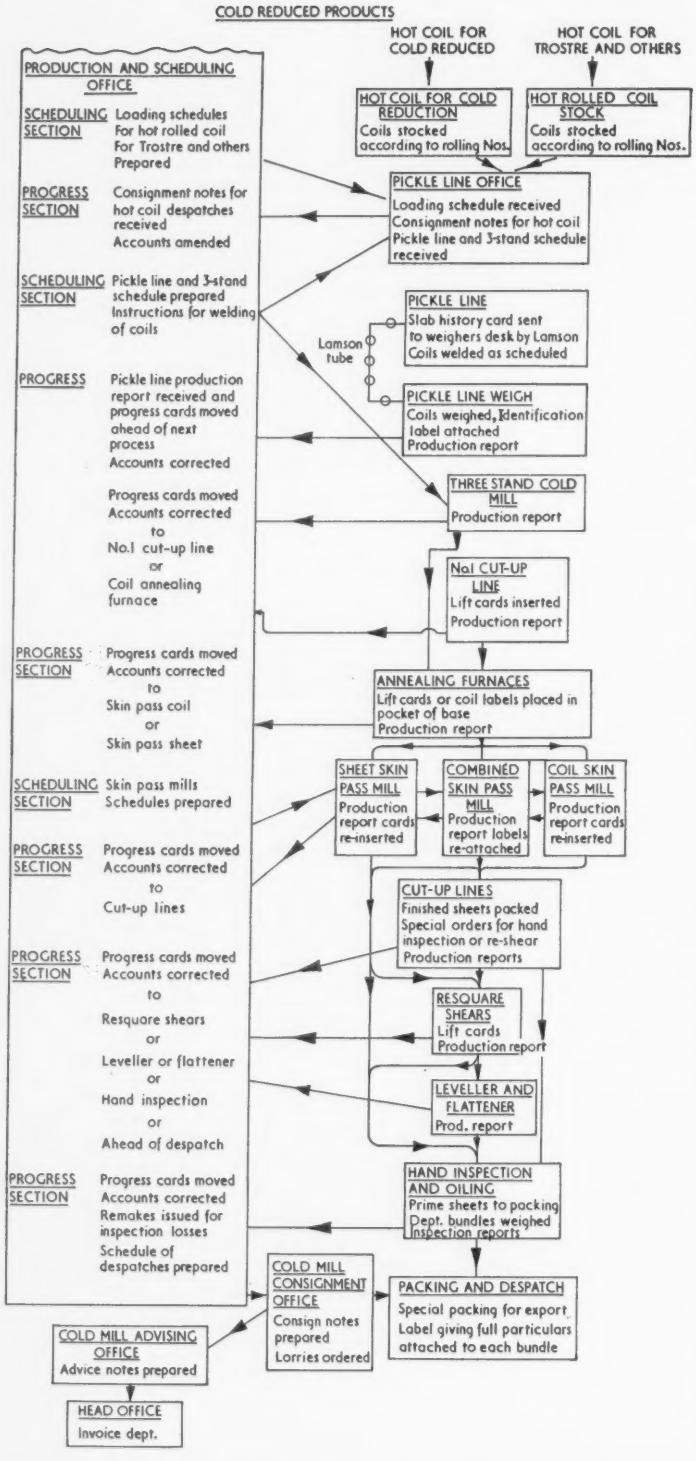

COLD REDUCED PRODUCTS
HOT COIL FOR COLD REDUCED
HOT COIL FOR TROSTRE AND OTHERS
PRODUCTION AND SCHEDULING OFFICE
SCHEDULING SECTION
Loading schedules For hot rolled coil For Trostre and others Prepared
PROGRESS SECTION
Consignment notes for hot coil despatches received Accounts amended
SCHEDULING SECTION
Pickle line and 3-stand schedule prepared Instructions for welding of coils
PROGRESS
Pickle line production report received and progress cards moved ahead of next process Accounts corrected
Progress cards moved Accounts corrected to No.1 cut-up line or Coil annealing furnace
PROGRESS SECTION
Progress cards moved Accounts corrected to Skin pass coil or Skin pass sheet
SCHEDULING SECTION
Skin pass mills Schedules prepared
PROGRESS SECTION
Progress cards moved Accounts corrected to Cut-up lines
PROGRESS SECTION
Progress cards moved Accounts corrected to Resquare shears or Leveller or flattener or Hand inspection or Ahead of despatch
PROGRESS SECTION
Progress cards moved Accounts corrected Remakes issued for inspection losses Schedule of despatches prepared
HOT COIL FOR COLD REDUCTION
Coils stocked according to rolling Nos.
HOT ROLLED COIL STOCK
Coils stocked according to rolling Nos.
PICKLE LINE OFFICE
Loading schedule received Consignment notes for hot coil Pickle line and 3-stand schedule received
PICKLE LINE
Slab history card sent to weighers desk by Lamson Coils welded as scheduled
Lamson tube
PICKLE LINE WEIGH
Coils weighed, Identification label attached Production report
THREE STAND COLD MILL
Production report
No.1 CUT-UP LINE
Lift cards inserted Production report
ANNEALING FURNACES
Lift cards or coil labels placed in pocket of base Production report
SHEET SKIN PASS MILL
Production report cards re-inserted
COMBINED SKIN PASS MILL
Production report labels re-attached
COIL SKIN PASS MILL
Production report cards re-inserted
CUT-UP LINES
Finished sheets packed Special orders for hand inspection or re-shear Production reports
RESQUARE SHEARS
Lift cards Production report
LEVELLER AND FLATTENER
Prod. report
HAND INSPECTION AND OILING
Prime sheets to packing Dept. bundles weighed Inspection reports
COLD MILL CONSIGNMENT OFFICE
Consign notes prepared Lorries ordered
PACKING AND DESPATCH
Special packing for export Label giving full particulars attached to each bundle
COLD MILL ADVISING OFFICE
Advice notes prepared
HEAD OFFICE
Invoice dept.

Fig. 3*b*—Flow of information: cold finished products

The dimensions of ingots related to the range of slab sizes to be produced determines the measure of work necessary by the mill per ton of steel converted, and therefore the design and number of moulds is of the first priority in promoting the highest possible rolling rates. The relationship between ingot and slab sizes should be calculated so as to avoid time lost by unnecessary manipulation. At the same time the ingot should be as heavy and as tall as possible within metallurgical restrictions. Slab sizes are calculated to produce the most strategic size of coil to the pickle line, cold-reduction mill, annealing furnaces, etc. The overall problem is further confused by the practice of allocating only the bottom portion of the ingot for certain high-grade and difficult pressings and by the need to cross-roll using short slabs in the strip mill to obtain widths over 62 in. Shortly after the mill had started, time studies were made to determine a formula which would assist in estimating the slabbing-mill rolling rates of ingots conceived in the above way. Table III shows the final data relating to the present ingot sizes.

The restraint imposed on the output of the strip mill and subsequent processes by cross-rolling warrants the maximum width of slab from the slabbing mill. It has been found at Abbey that an additional 5 in. of lift can be obtained by altering the roll chocks; and a 76-in. wide ingot has therefore been designed, which will be rolled only on the flat until 12 in. thick, to enter the 14-in. edging hole. The 6-in. hole will be eliminated. This alteration will increase the maximum width of slab from 62 to 70 in.

Whilst mechanical and electrical breakdowns are troublesome on most mills, feeding the mill with hot ingots and time out of rolls are the prime causes of a modern slabbing mill failing to sustain rolling rates (*see* Table III). Time out of the rolls is directly related to the reversing times of the mill motors, screwdown speeds, and time absorbed by manipulation. Tandem rolling or semi-tandem has at least 15% beneficial effect and is really a compromise to the limited height of an individual ingot imposed by the steelplant. The universal mill is the answer to time lost by manipulation and edging passes. The provision of vertical rolls also renders

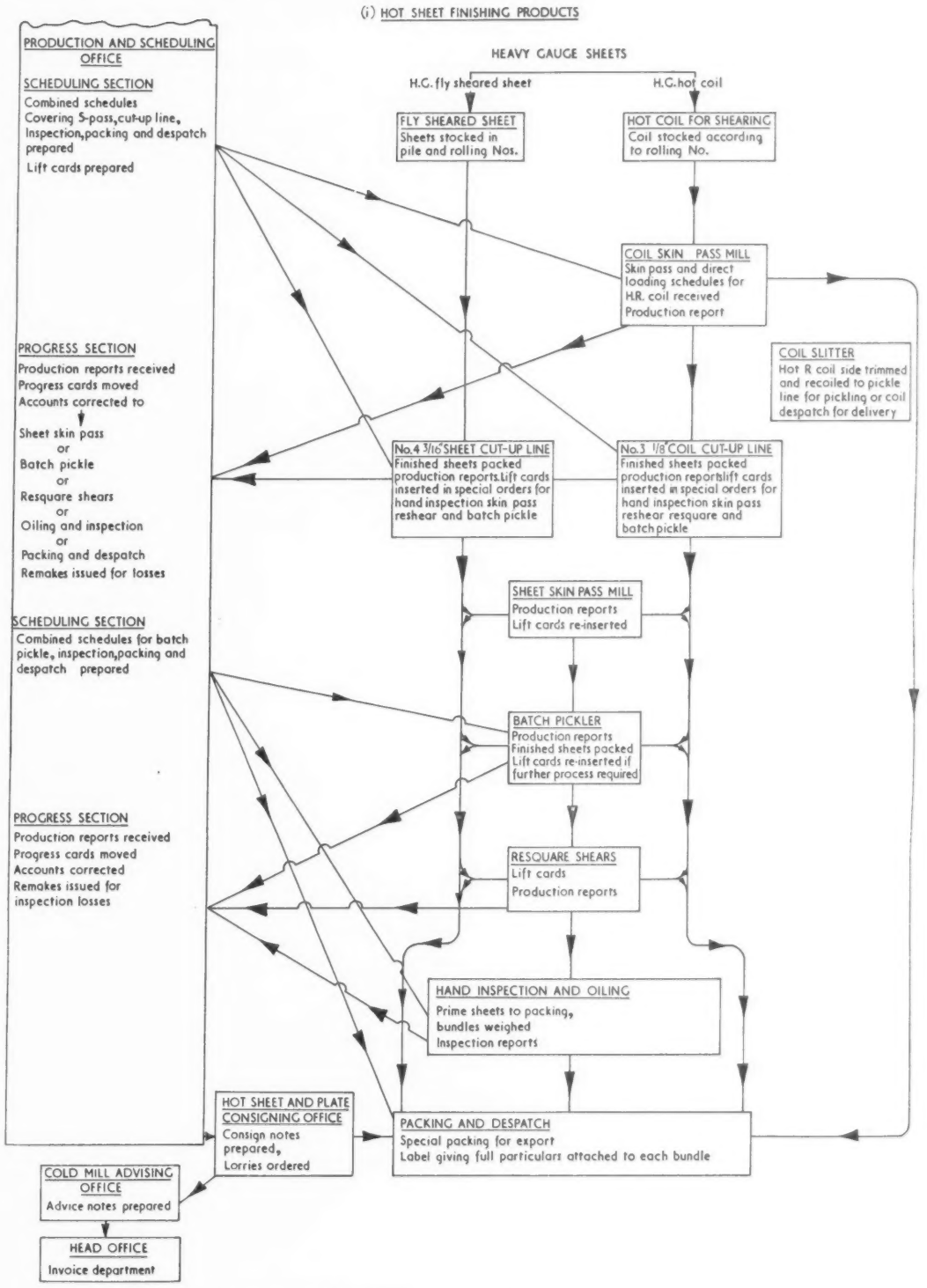

(i) HOT SHEET FINISHING PRODUCTS
PRODUCTION AND SCHEDULING OFFICE
SCHEDULING SECTION
Combined schedules Covering 5-pass, cut-up line, Inspection, packing and despatch prepared
Lift cards prepared
PROGRESS SECTION
Production reports received
Progress cards moved
Accounts corrected to
Sheet skin pass or Batch pickle or Resquare shears or Oiling and inspection or Packing and despatch
Remakes issued for losses
SCHEDULING SECTION
Combined schedules for batch pickle, inspection, packing and despatch prepared
PROGRESS SECTION
Production reports received
Progress cards moved
Accounts corrected
Remakes issued for inspection losses
HEAVY GAUGE SHEETS
H.G. fly sheared sheet
H.G. hot coil
FLY SHEARED SHEET
Sheets stocked in pile and rolling Nos.
HOT COIL FOR SHEARING
Coil stocked according to rolling No.
COIL SKIN PASS MILL
Skin pass and direct loading schedules for H.R. coil received
Production report
COIL SLITTER
Hot R coil side trimmed and recoiled to pickle line for pickling or coil despatch for delivery
No. 4 3/16" SHEET CUT-UP LINE
Finished sheets packed production reports. Lift cards inserted in special orders for hand inspection skin pass reshear and batch pickle
No. 3 1/8" COIL CUT-UP LINE
Finished sheets packed production reports lift cards inserted in special orders for hand inspection skin pass reshear resquare and batch pickle
SHEET SKIN PASS MILL
Production reports
Lift cards re-inserted
BATCH PICKLER
Production reports
Finished sheets packed
Lift cards re-inserted if further process required
RESQUARE SHEARS
Lift cards
Production reports
HAND INSPECTION AND OILING
Prime sheets to packing, bundles weighed
Inspection reports
HOT SHEET AND PLATE CONSIGNING OFFICE
Consign notes prepared,
Lorries ordered
PACKING AND DESPATCH
Special packing for export
Label giving full particulars attached to each bundle
COLD MILL ADVISING OFFICE
Advice notes prepared
HEAD OFFICE
Invoice department

Fig. 3c (i)—Flow of information: hot sheet finishing products

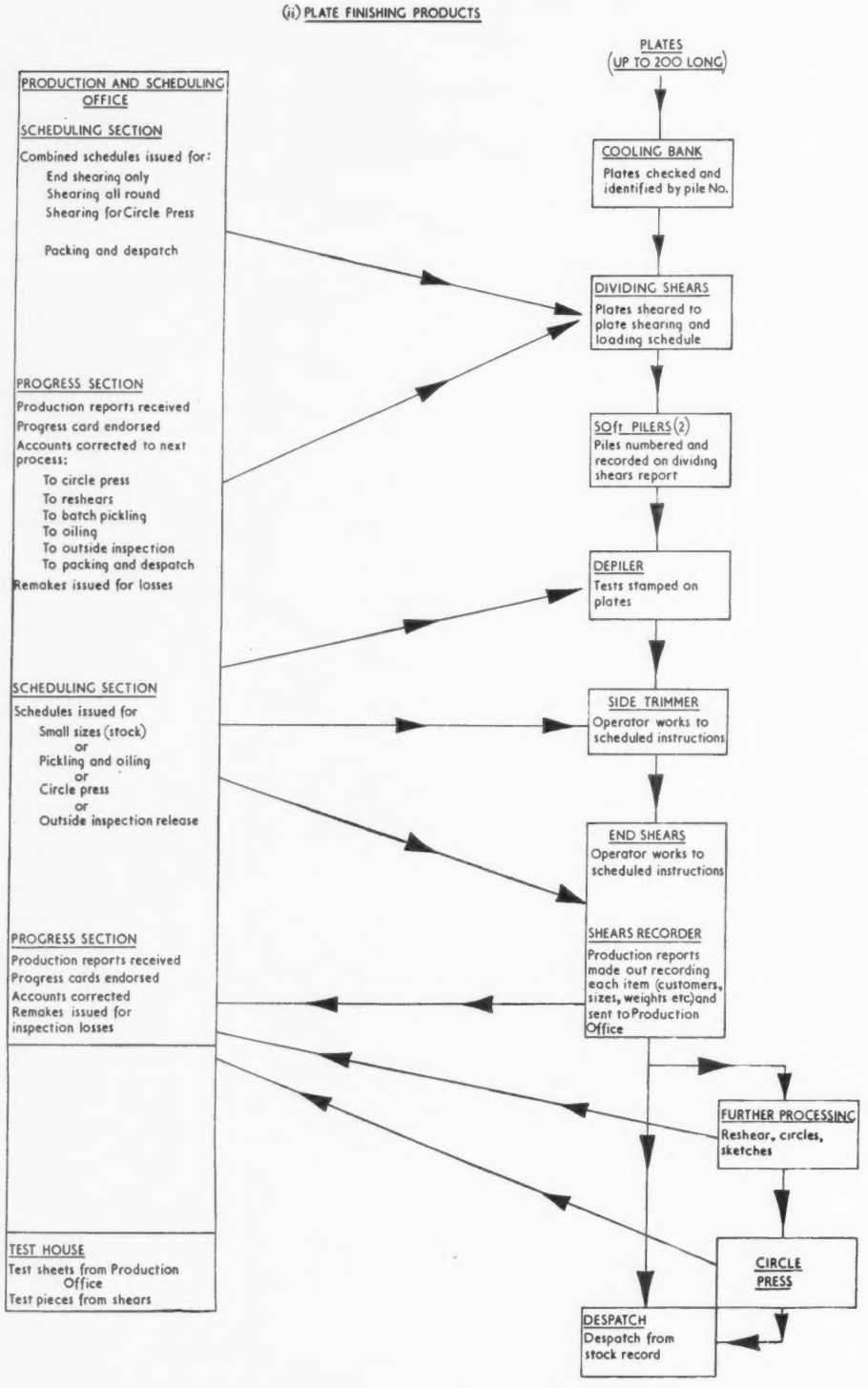


Fig. 3c (ii)—Flow of information: plate finishing products

Table III—INGOT MOULDS

Mould Type and Size	Proposed or Existing	Width Range, in.	Slabbing Mill, Rolling Rate, tons/h	Strip-Mill Slab Thickness Range, in.	Weight per Slab, lb	Pickle Line	3-Stand Mill: Weight of Coil, lb	Annealing
18·6 tons, 76 in. × 29 in.	Existing	72–62	Single 575	2 longs 5–5½	17,500	Weld 3 coils	52,500	Max. weight with diameters of 63–66 in.
				4 shorts 5–5½	8750	Weld 6 coils	52,500	Generally for sheet-anneal
				1 long, 1 short 7–7½	Bottom 23,000	Weld 2 coils	46,000	Under max. weight, with diameters of 60–63 in.
					Top 12,000	Discard		
14 tons, 67¾ in. × 29 in.	Existing	61–55	Single 506 Tandem 724	1 long 8–8½	28,000	Weld 2 coils	56,000	Max. weight with diameters of 69–72 in.
				1 long, 1 short 6–6½	Bottom 18,000	Weld 3 coils	54,000	Max. weight with diameters of 68–71 in.
					Top 10,000	Discard		
12 tons, 59¾ in. × 29 in.	Existing	54–48	Single 440 Tandem 630	1 long 8–8½	24,000	Weld 2 coils	48,000	Diameters of 69–72 in.
				1 long, 1 short 5½–6½	Bottom 16,000	Weld 3 coils	48,000	Diameters of 69–72 in.
					Top 8000	Discard		
11·5 tons, 53 in. × 27 in.	Existing	47–42	Single 404 574	1 long 7½–8½	22,000	Weld 2 coils	44,000	Diameters of 70–72 in.
				1 long, 1 short 6–6½	Bottom 14,000	Weld 3 coils	42,000	Diameters of 69–71 in.
					Top 8000	Discard		
10 tons, 48 in. × 29¾ in.	Existing	42–38	Single 377 Tandem 531	1 long All 8½	20,000	Weld 2 coils	40,000	Diameter of 70–72 in.
				1 long, 1 short 6–6½	Bottom 13,000	Weld 3 coils	39,000	Diameter of 69–72 in.
					Top 7000	Discard		
15 tons, 53 in. × 36¼ in.	Proposed	37–31	Single 305 Semi-tandem 361	2 ongs 7½–8½	16,000	Weld 2 coils	32,000	Diameters of 69–72 in.
12 tons, 49 in. × 28½ in.	Proposed	30–27	Single 304 Semi-tandem 341	2 longs 7½–8½	14,000	Weld 2 coils	28,000	Diameters of 69–72 in.
8 tons, 41½ in. × 24½ in.	Existing	37–27	Single 116 Tandem 159	1 long (limits of 37–29 in.) 7–8½	16,000	Weld 2 coils	32,000	Diameters of 67–72 in.
				3 shorts or 1 long, 1 short 5–6½	5500	For plate or if bottom-cut for coil: weld 3 coils	30,000	Diameter of 65–72 in.
15 tons, bottle-top, 51 in. × 36¼ in. × 78 in.	Existing	45–31	Single 373 Semi-tandem 310	6–8½	15,000			
12 tons, bottle-top, 49 in. × 28¼ in. × 81 in.	Existing	43–27	Single 304 Semi-tandem 341	5–8½	12,500			

Note: With regard to the calculations for coil weights for the 3-stand and annealing furnaces, these weights can only be achieved by rolling on the strip mill an order (or combination of orders) calling for a minimum poundage equal to the weight of the product of either the single slab, or the bottom-cut slab of the ingot, in the appropriate width range.

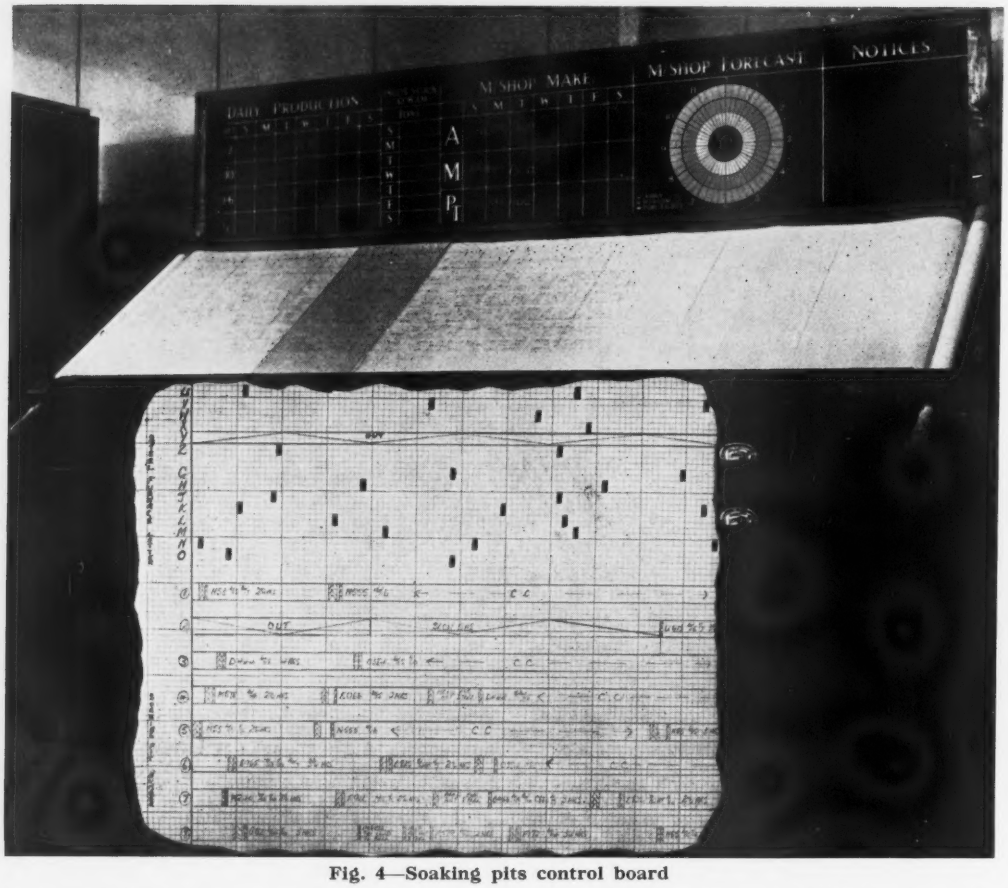


Fig. 4—Soaking pits control board

ingot design independent to a greater extent of the width factor. Furthermore, the act of rolling four sides simultaneously is advantageous to quality and shape.

The angle of bite of 45-in. rolls permits draughts up to 3½ in. and, assuming that the torque of the mill can accept this load, the screwdown speeds should have sufficient acceleration and braking to travel this distance in the equivalent time taken by the roll-driving motors to reverse. It is difficult to say precisely what these quantities should be to obtain the fastest possible rolling rates and at the time of writing, the Company's Operational Research Department, in conjunction with B.I.S.R.A., are carrying out a detailed study. The speed of the slabbing mill rolls obviously has a significant effect on rolling rates, but offers little or no advantage over 50 rev/min. Because of an electrical breakdown on one of the four generators supplying the mill motors, the maximum mill speed was on one occasion reduced to 20 rev/min. In spite of this, 32,000 tons of ingots were rolled in 17 shifts.

Time spent in changing rolls after a campaign of, for example, 70,000 tons offers scope for work study. Without debating the merits of counterweight or hydraulic roll-balance systems, it is manifest that the counterweight calls for improved design of latching. The difficulty of entering the roll couplings into the spindles is the greatest delaying manœuvre, and a hydraulic jack should be provided for the final alignment of the top spindle. Although broken rolls are happily few, mill designers have paid little regard to the method of extracting the broken pieces. Knurling of rolls assists entry of the piece and avoids skidding during heavy reductions. It is also claimed that the surface quality of the slab is improved.[4] At Abbey, the mill started with knurled rolls, but it was discontinued because fire cracking started at the roots of the pattern. It has now been reintroduced using a staggered pattern.

Separators are provided on the top of the bottom chocks which can be burnt through should the top roll run down out of control owing to an electrical fault or to the mistake of an operator. Designers do not provide enough margin between the top working position of the chocks and the underside of the mill housing, which would enable a limit switch to slow down and halt the screw motors before jamming in the event of faults or accidents.

A well designed slabbing mill such as at Abbey is not difficult to maintain, and, apart from major breakdowns due to accidents, etc., lost time has been confined to wear on the screws, failure of feed-roller drives, and stretching of holding-down bolts on the table

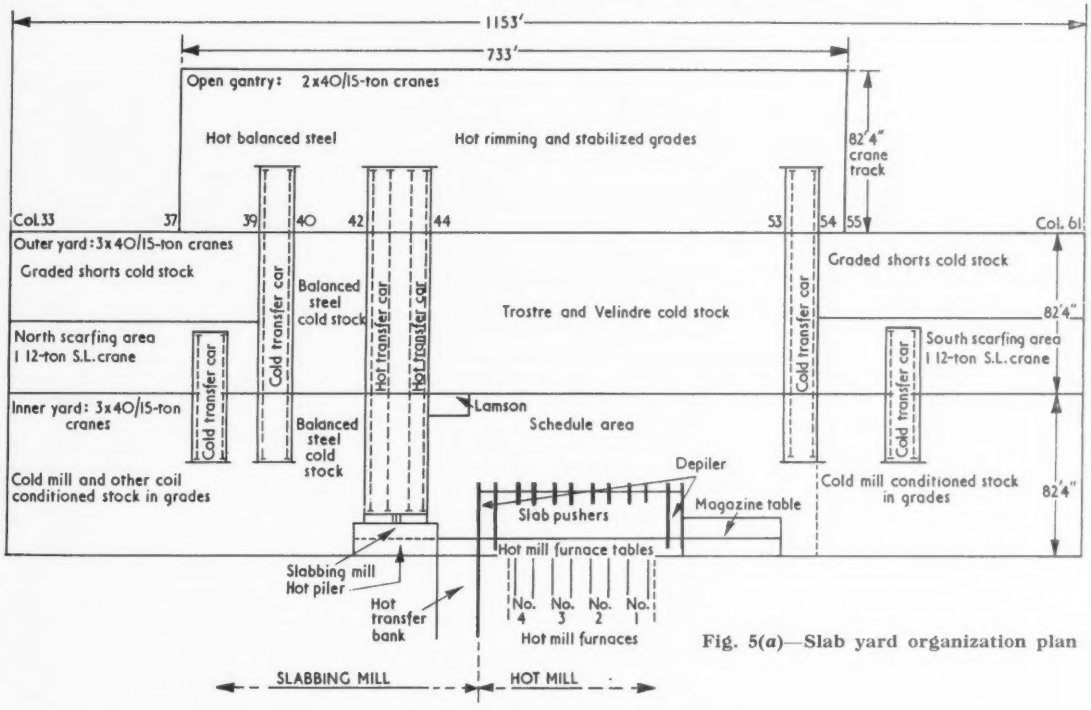


Fig. 5(*a*)—Slab yard organization plan

rollers. Feed rollers (the first four rolls front and back) should be individually driven and each individual thread of the roll-setting screws should be lubricated. Design of feed tables subject to heavy shock loading is still undecided and the need for weekly inspection of holding down bolts inside gear cases at Abbey[5] suggests that individual motors for each roller would be the most dependable.

SLAB YARDS

The hot-rolling schedule for a wide strip mill calls for considerable organization in the slab yards, which provide the service of stocking, inspection, hand-scarfing, and charging to the furnaces in the sequence required. This demands a large stock of slabs to enable the scheduler to make the most efficient use of the mill and at the same time to meet the selling allocation agreed for the various finishing departments of the company. Whilst there are considerable advantages to be derived by the strip mill from carrying a large stock of slabs, it becomes a considerable test of organization to ensure that slabs of the many grades and qualities can be located and handled in the time permitted. At Abbey, rolling up to 33,000 tons per week, a slab stock of 20,000 tons seems to be ideal. However, this creates a difficulty for the melting shops because they have to make the steel close to the time of the week required to meet the strip-mill conditions. Casts out of specification cannot be so readily applied against current orders and are therefore rolled to orders ahead of time or rolled into stock. Figure 5*a* shows for three bays the organization plan to be introduced after a new outer gantry has been completed. To increase crane utilization, one of the two depilers serving the slab furnaces should have the assistance of a magazine table when mill outputs in excess of 35,000 tons are envisaged.

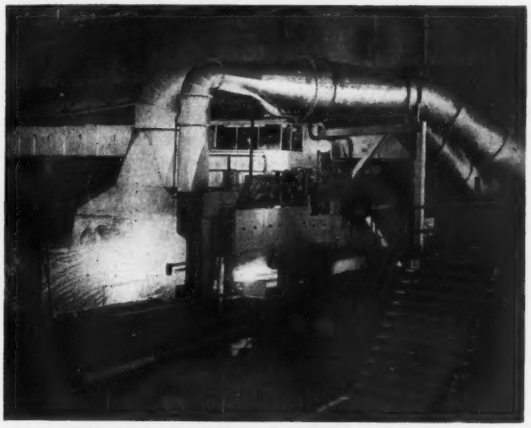


Fig. 5(*b*)—Scarfing machine in operation

Automatic scarfing (Fig. 5*b*) after the slabbing mill will reduce the cost of hand-scarfing in the slab yards and lend flexibility in supplying the slab furnaces more quickly. The advantages of automatically scarfing the surfaces of slabs do not apply, of course, where the quality of steel rises to an optimum.

SLAB REHEATING FURNACES

The greatest influence on the output of the hot strip mill is the availability of the slab furnaces. Until recently there have been three in use and the fourth

Table IV

HOT STRIP MILL ROLLING SCHEDULE.

SHEET No. 3.
ROUND No. 2.
5.2845.

DATE W.E. 26th March, 1955.

194.

Rolling No.	Order No.	Grade	Cast	No. of Slabs	Slab Size: Width	Slab Size: Thickness	Slab Size: Length	Hot Strip Size: Width	Hot Strip Size: Gauge	Hot Strip Size: Length	Finish	Special Instructions	Customer	No. Rolled	Slab Weight (Pounds)	Rolled Weight (Pounds)	Cobbles: No.	Cobbles: Weight (Pounds)
C44172	WS. 1 9211	020B	021	2	50	6	8.	64¾	100	F.F.	036	Pin 1610/1650 Coil Cold 1200	M. Panels		16,000		A	749
C44173	WS. 2 10	030 T & B	030	4	"	"	"	"	105	G.F.	042	" " "	F. Steel		32,000		A	747
C44174	WS. 2 9602	020B	021	2	"	"	"	66¾	100	F.F.	036	" " "	Nuffield		16,000		A	749
C44175	WS. 1 9970	612	612	4	58	"	"	"	100	F.F.	039	Pin 1610/1650 Coil Cold 1100/1200	Fisher & Ludlow		36,000		100%	631
C44176	S. 1 4753	020B	031	4	"	"	"	"	100	"	041	Pin 1610/1650 Coil Cold 1200	Vauxhall		52,000		A	725
C44177	S. 1 4753	030B	"	2	50	6	"											776
C44178	WS. 1 16	611	611	2	"	"	"	67½	100	"	036	Pin 1610/1650 Coil Cold 1100/1200	F. Steel		106,000		100%	696
		611		9	58	6	"											3 2 6 773/631/653
		612		1	"	"	"											692
C44179	WS. 1 9953	611	611	7	"	"	"	68½	100	"	039	" " "	Fisher & Ludlow		63,000		100%	6 1 620/653
C44180	WS. 1 4996	611	611	2	"	"	"	72½	100	GF	036	" " "	Ford Motor.		18,000		100%	631
C44181	WS 3 177	612	611	15	"	"	"	"	100	F.F.	036	" " "	Car Bodies.		135,000		100%	602
C44182	WS 1 8832	612	"	4	"	"	"	"	100	"	036	" " "	Airflow.		36,000		100%	3 588
C44183	WS 1 112	020B	021	2	57	6	"	"	100	"	039	Pin 1610/1650 Coil Cold 1200	M. Panels.		18,000		A	725
C44184	WS 5 9626	612	611	10	50	6	"	67½	100	"	036	Pin 1610/1650 Coil Cold 1100/1200	Jaguar.		90,000		100%	538
C44185	WS 1 9219	611	611	12	58	6	"	66¾	100	"	041	" " "	Austin.		106,000		100%	10 2 653/631
C44186	SK. 11 7167	611	"	3	50	6	"	65¾	100	"	049	" " "	Svenska.		54,000		100%	631
		612		3	"	"	"						"					602
C44187	SK. 8 7167	612	611	8	"	"	"	65¾	100	"	039	" " "	"		70,000		100%	538
C44188	S. 2 4723	612	611	6	"	"	"	61½	093	"	041	" " "	B.L.S.F.		48,000		100%	588
C44189	S. 7 4723	020B	021	4	"	"	"	61¾	"	"	036	Pin 1610/1650 Coil Cold 1200	"		36,000		A	725
C44190	WS. 1 8833	020F	060	12	54	5½	"	54	080	Coil	HSF		Allen		96,000		BE	7 3 656/724
BE44191	WS 2 8572	030T	050	2	55	6	"	55¾	072	"	"	Pin 1580/1640 Coil Cold 1100/1200	Dunlop		16,000		BE	222
BE44192	S. 2 2124	025	060	1	55	6	1.	55	078	"	"		Perkins.		16,000		BE	745
				121											1,060,000			

C.R. 932,000
HOC 128,000

/PG.

will shortly come into commission to meet the greater demand when steel supplies have been augmented at the end of 1955. The availability of furnaces is largely a problem of refractories, but it is also affected by combustion and avoidance of slag, the removal of which requires the furnace to be idle.

Availability is also affected by erosion of the 73% alumina brick hearth. Hearth life has been increased from 5 to 9 months (360,000 tons per hearth), by redeploying the old Cr–Ni skids taken from the previous campaign midway between the original positions which are in line with the water-cooled skids. Further improvements approaching U.S. performance are expected by using forged or rolled 25/12 Cr–Ni skids in place of the present 29/0·3 type. Reduction in numbers of the short slabs already mentioned will reduce the centre wear of the hearth caused by shear drags.

The normal rating of a modern continuous slab furnace of the Rust type is approximately 110 tons/h heating slabs measuring 18 ft long by 6–7 in. thick. This figure relates to cold steel and it has been found when charging hot steel which has cooled after slabbing to say 1500° F that the furnace capacity has been increased by over 30%. Slab furnace length appears to have standardized at approximately 85 ft. Exhaust gases before entering the recuperators are at 1500° F, and increased length might provide greater heating rates per furnace, together with improved thermal efficiency from using the exhaust gases for pre-heating.

With dual-firing oil and/or coke-oven gas the burner construction must afford ease of cleaning when returning to oil from gas. The first guns used at Abbey were front-atomizing, but have been changed to back-atomizing for this reason. The pressure and temperature of oil used is 90 lb/in² and 130–200° F respectively, and steam pressure is approximately 70 lb/in². On the three older furnaces there are eight burners in the soak zone, six in the top tonnage zone, and five in the lower tonnage zone. On the new furnace there are eight burners in the soaking zone, six in the upper tonnage zone, and eight in the lower tonnage zone. Four of the burners in the soak zone in the new furnace are grouped in pairs to enable the centre burner to be shut off when heating shorts, thus avoiding the centre build-up of slag. High-sulphur oil (approx. 4%) is under trial and offers an attractive saving of £1 per ton of oil used. However, fumes are obnoxious to personnel under certain atmospheric conditions and it is too early to offer an opinion on the possibility of H_2SO_4 being deposited and attacking steelwork.

Table V
ROLL CHANGING DATA AND CROWNS
Abbey 80-in. hot strip mill

Stand	Work Rolls			When Changed	Back-up Rolls		When Changed	Crowns	Order of Changing Back-up Rolls									
	Aver. Max. Dia., in.	Aver. Max. Dia., in.	Barrel Length, in.		Aver. Max. Dia., in.	Aver. Max. Dia., in.			1st week	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
R.S.B.	36	32	72	Every 4 weeks	...	...	4 weeks	Parallel			X				X			
R.1 (broad-side)	42	38	130	,,	54	50	Every 8 weeks	0·025 top 0·025 bot.	BU X WR				X WR				BU X WR	
R.2	36½	34½	80	Every week	54	50 or less	Every 4 weeks	0·010 top only		X				X				X
R.3	36½	34½	80	,,	54	,,	,,	0·010 top only			X				X			
R.4	25·8	25·5	80	Every G.R.C.	54	,,	,,	0·005 top only										
F.5	26	25·8	80	Every G.R.C. and for surface	Top 54 Bot. 54	52 50	Every 2 weeks	0·005 top only		X		X		X		X		X
F.6	26½	26	80	,,	,,	,,	,,	0·008 top only		X		X		X		X		X
F.7	26½	26½	80	,,	,,	,,	,,	0·010 top only	X		X		X		X		X	
F.8	26½	26½	80	,,	,,	,,	,,	0·012 top only	X		X		X		X		X	
F.9	27½	26½	80	,,	54	53 top and bot.	Every week	0·012 top only	X	X	X	X	X	X	X	X	X	X
F.10	27½	27½	80	,,	,,	,,	,,	0·010 top only	X	X	X	X	X	X	X	X	X	X

Note: It has been found that excellent shape is obtained on wide material when the back-ups on F.7, F.8, F.9, and F.10 are changed at the same time. When F.5, F.6, F.9, and F.10 are changed, edge work is produced out of No. 7 mill. To overcome this, the top rolls have been reduced in F.5 and F.6 to parallel for the week when F.5, F.6, F.9, and F.10 back-ups are changed, reverting to normal the following week.

The speed at which a furnace can be recommissioned after being idle for repairs is considerably influenced by the time taken to cool down to a temperature which will not unduly distress men engaged on repair. The air fan can be used to evacuate the furnace assisted by additional blowers, coupled with full flow of cooling water through the skid pipes. An efficient cooling system (such as heat exchangers) has therefore a double advantage to those plants not endowed with unlimited fresh water, as in the case of the more fortunate mills sited on lakes in the U.S.A. The idea of using steam in place of water has an obvious disadvantage during furnace repairs.

The standardization of slab thickness plays an important part in utilizing the maximum capacity of the furnace, as the heat input must be equal to that required for the thickest slab; thus thinner slabs charged into the furnace would become overheated or *vice versa*. Whilst the Abbey furnaces were designed for 105 tons/h on 6-in. slabs, higher outputs are obtained from slabs in excess of this thickness. To provide greater coil weights, slab furnaces of the future may have to accept slabs up to 25 ft long and/or over 8½ in. thick.

HOT STRIP MILL (TABLE II)

So many laymen ask the intelligent and obvious question, " Why do you let the slab go cold before rolling in the strip mill ? " The reasons are:

(*a*) Inspection and dressing of the slabs
(*b*) Scheduling of the hot strip mill.

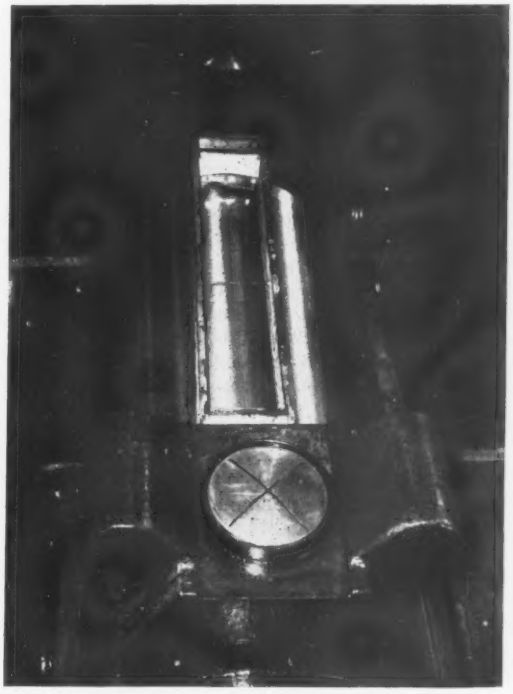


Fig. 6—Water box on back-up roll (hot strip mill)

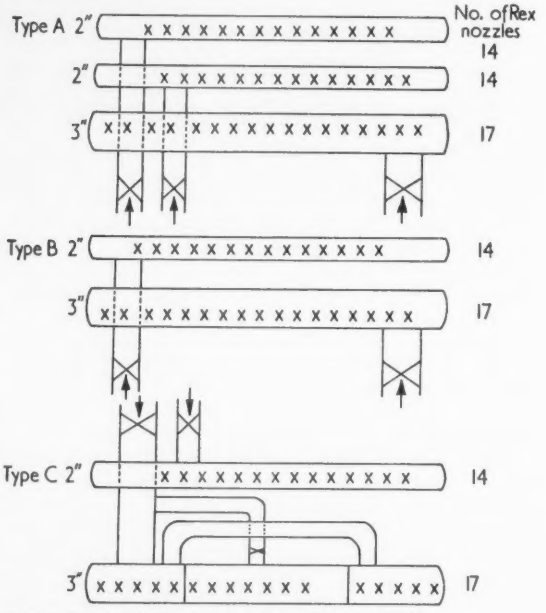
Fig. 7—View of (*a*) top-roll, (*b*) bottom-roll coolant sprays with roll removed (hot strip mill)

Otherwise, it is possible to roll directly from the slabbing mill and finish from No. 10 stand at a temperature of 1650° F.

The installation of an automatic scarfing machine at the slabbing mill for dressing the four sides of the slabs when necessary whilst hot eliminates the first obstacle. However, it remains to coincide the receipt of specific casts from the steelplant with the time they can be ultimately delivered from the soaking pits to meet the exact item on the hot strip mill schedule. However, the standard widths and large quantities of tinplate do lend this product to such a practice and enables the strip mill to become less dependent upon reheating.

The hot strip mill schedule (Table IV) is the commercial and technical programme upon which output and to some extent quality are based. Although the elasticity or distortion of a mill assembly is a constant, the effect on roll setting and speed synchronization of roll wear, roll temperature, strip temperature, and hardness cannot be accurately predicted; the mill schedule must therefore avoid violent changes from one item to another, either in width or gauge (or both), and reduce the chance of error in the operators' judgement of mill settings. The schedule is planned to begin with a narrow width, widen out rapidly to a given maximum, and slowly return over an output of approximately 3000–3500 tons; this has been found by experience to compensate roll wear from the point of view of both shape and surface quality. Roll wear takes place not only on the work rolls but also on the back-up rolls, but whilst the top work rolls are crowned to compensate for wear, the back-ups are parallel. In view of proportionately less wear on back-up rolls these are changed at longer intervals according to the plan shown in Table V, which also shows the crowns used for the work rolls. During a 4000-ton schedule, it is necessary to change Nos. 5, 6, 7, and 10 mills at intermediate stages to maintain surface finish before the final complete change at the end of the schedule.

It is an interesting point and opposed to earlier remarks in this paper that a wide strip mill can suffer from over-standardization. In the case of tinplate, both in this country and in the U.S.A., the common width range falls between 29 and 32 in. and, as a result of roll wear, it is essential to roll not more than 450 tons for every inch of width of roll face, otherwise an inferior edge will cause trouble later in the 5-stand mill. In the case of a hot mill producing more than 20,000 tons of tinplate plus narrow-width sheet orders in a week, corresponding roll changes become excessive in relation to optimum output.



Type A: In use on bottom entry headers on F.5 and F.6 mills

Type B: In use on:
Top entry headers on F.5, F.6, and F.10 mills
Top delivery headers on F.5 and F.6 mills
Bottom entry headers on F.7, F.8, F.9, and F.10 mills
Bottom delivery headers on F.5, F.6, F.7, F.8, F.9, and F.10 mills

Type C: In use on:
Top entry headers on F.7, F.8, and F.9 mills
Top delivery headers on F.7, F.8, F.9, and F.10 mills

	F.5		F.6		F.7		F.8		F.9		F.10	
	En.	Del.	En.	Del.	En.	Del.	En.	Del.	En.	Del.	En.	Del.
Top headers (type)	B	B	B	B	C	C	C	C	C	C	B	C
Bottom headers (type)	A	B	A	B	B	B	B	B	B	B	B	B

Fig. 8—Diagram and table of cooling sprays

In view of the many roll changes during a week and for which an output of 40,000 tons may require 320 rolls, it is vital that this exercise should be reduced to the minimum possible time. The shortest period so far at Abbey is seven pairs of work rolls taken out and replaced in 27 min. Two cranes are used, and in the case of trouble with the hydraulic pullbacks a third crane assists. Hydraulically operated pullbacks save time, except when they go wrong, and in view of their location they present a difficult maintenance problem. A more simple design in the end may be the best. It has been found that the forced-feed lubrication connections can be left off the roller-bearings of the work rolls, the latter having been pressurized in the roll shop, and considerable time is saved in this way during roll changing.[6] Levelling of the mills using hand gauges or other manual methods costs time, and experiments are shortly to begin at Abbey using loadmeters.

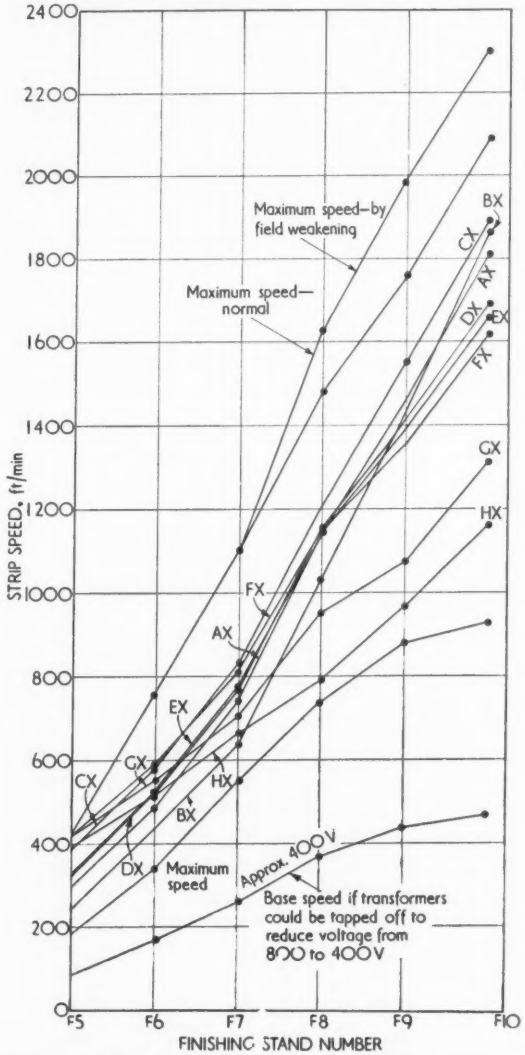


Fig. 9—Hot strip mill speed cone

The number of roll changes is also related to the quality of the rolls,[7] water application on the mill, and quality of strip produced. Work rolls are of chilled iron alloy and back-up rolls are of cast steel. The hardness of the work rolls in the final three stands is 80–85° Shore; they are moved back as the hardness is gradually reduced with the diameter. Steel work rolls are being tried in stands 5 and 6, whilst a water spray applied to the strip between Nos. 5 and 6 extends the life of No. 6 mill rolls and improves the final surface of the strip. Back-up rolls are of cast steel and sleeved rolls using turned down solid rolls as arbors are being tried.

Water for roll cooling is applied to the back-up rolls by means of a water box (Fig. 6) and to the work rolls via sprays (Fig. 7). Figure 8 shows the arrangement of the cooling sprays on the work rolls for each mill. The bottom rolls of Nos. 5 and 6 mills have the largest volume of water and this arrangement was found to be necessary to arrest a spate of broken rolls due to overheating. Rolling $8\frac{1}{2}$-in. slabs at over 400 tons/h causes the strip to be in contact with these two mills for a considerable time at low speed. Variable headers are arranged on the last four mills to provide an operator with a somewhat limited method of compensating for the effect of roll temperature and wear on the profile of the roll in relation to shape. The total water available for roll cooling is 3000 gal/min at 100 lb/in^2, for Nos. 4, 5, 6, 7, 8, 9, and 10 mills and 1500 gal/min at 40 lb/in^2 for roughing stands. Careful design of and attention to wipers on the finishing mills, thereby preventing excess water from resting on the strip, avoids bad shape resulting from local loss of temperature.

Rolled-in scale and roll wear are the enemies of surface quality. After many trials and errors it has been found at Abbey that descaling single headers top and bottom on the front side of Nos. 2, 3, and 4 roughing mills, double headers top and bottom on the front side of No. 5 finishing mill (counting No. 10 as the last), and single headers on the back side of the primary scale breaker provide satisfactory descaling efficiency as long as the pressure does not fall below 1200 lb/in^2, and the angle and distance of the jets relative to the piece are optimum. Four pumps are provided, each of 1000 gal/min, and normally two are in use. Manpower is saved by operating the sprays by a signal from a photo-electric cell.

The maximum slab thicknesses of $8\frac{1}{2}$ in. on certain widths represents the limit which the power of the roughing mills can comfortably handle. Heavy reduction by the broadside mill of 35% causes severe spread and it is necessary to roll the slab underwidth at the slabbing mill to avoid excessive work on the edging mill in front of No. 2 stand. The squeezer between the broadside and No. 2 stand at Abbey is too short and advantage cannot be taken to true up a slab longer than 12 ft. The influence of large coils on all processing units is of such importance as to warrant the use of slabs thicker than $8\frac{1}{2}$ in. and/or longer than 18 ft; and if this can only be achieved in future mills by additional stands either to the roughing or finishing mills, the equivalent to the additional capital investment may be more than retrieved by capital savings on supplementary processes.

Table VI

ROLL SETTING

80-in. hot strip mill: R.4 to F.10 mills

Slab Size, in.	Finished Section, in.	Grade	Stand No.	Mill Setting	Actual Gauge	Spring	ft/min	rev/min	Load, A	Roll Diameter, in.
58 × 6	73 × 0·250		R.4	950	...	...	...	...	...	...
,,	,,		F.5	595	717	122	393	262	6000	26·708
,,	,,		F.6	416	543	127	518	192	5800	26·880
,,	,,		F.7	340	427	87	664	94	5800	26·819
,,	,,		F.8	265	359	94	791	112	5200	26·790
,,	,,		F.9	190	294	104	967	137	4900	27·335
,,	,,		F.10	225	250	25	1160	162	2700	27·365
39 × 5	40 × 0·105	020	R.4	875	875	...	...	...	...	...
,,	,,	,,	F.5	430	505	75	390	260	4800	26·001
,,	,,	,,	F.6	200	340	140	580	215	4600	26·850
,,	,,	,,	F.7	88	239	151	833	118	4600	26·890
,,	,,	,,	F.8	60	164	104	1214	172	4600	27·004
,,	,,	,,	F.9	30	128	98	1553	220	4200	27·106
,,	,,	,,	F.10	84	105	21	1892	268	2000	27·385
58 × 6	71 × 0·100	611	R.4	875	...	...	...	...	...	...
,,	,,	,,	F.5	346	489	143	330	220	6500	25·922
,,	,,	,,	F.6	105	306	201	526	195	6800	26·903
,,	,,	,,	F.7	12	210	198	777	110	7100	26·862
,,	,,	,,	F.8	9995	143	148	1144	162	6000	26·894
,,	,,	,,	F.9	9980	117	137	1398	198	5400	27·037
,,	,,	,,	F.10	32	100	68	1660	234	2200	27·405
67 × 5	66 × 0·093	020	R.4	900	...	...	...	...	...	...
,,	,,	,,	F.5	320	478	158	327	218	...	25·922
,,	,,	,,	F.6	95	299	204	521	193	...	26·903
,,	,,	,,	F.7	9998	203	205	770	109	...	26·862
,,	,,	,,	F.8	9983	135	152	1158	164	...	26·894
,,	,,	,,	F.9	9970	110	140	1419	201	...	27·037
,,	,,	,,	F.10	24	093	69	1690	238	...	27·405
29½ × 7	30¼ × 0·090	050	R.4	1·000	1·000	...	...	...	...	...
,,	,,	,,	F.5	390	540	150	300	200	4600	26·012
,,	,,	,,	F.6	153	322	169	486	180	4000	27·300
,,	,,	,,	F.7	15	220	205	741	105	3200	26·311
,,	,,	,,	F.8	9992	144	152	1144	162	3500	26·787
,,	,,	,,	F.9	9970	105	135	1461	207	2700	27·484
,,	,,	,,	F.10	50	086	036	1810	255	1400	27·470
58 × 6	73 × 0·125	029	R.4	·925	·925	...	...	...	...	...
,,	,,	,,	F.5	370	475	105	423	282	7600	25·859
,,	,,	,,	F.6	165	337	172	594	220	6800	27·004
,,	,,	,,	F.7	58	248	190	812	115	6200	26·767
,,	,,	,,	F.8	31	175	144	1151	163	5800	26·682
,,	,,	,,	F.9	18	149	131	1356	192	5800	27·137
,,	,,	,,	F.10	57	125	68	1620	228	3000	27·273
58 × 6	73 × 0·188	200	R.4	925	925	...	...	...	...	...
,,	,,	,,	F.5	500	573	73	421	281	6400	25·859
,,	,,	,,	F.6	278	431	153	553	205	5800	27·004
,,	,,	,,	F.7	160	338	178	706	100	5800	26·767
,,	,,	,,	F.8	125	251	126	953	135	5400	26·682
,,	,,	,,	F.9	95	222	127	1073	152	4800	27·137
,,	,,	,,	F.10	121	188	67	1310	180	2800	27·273
33 × 8	34 × 0·085	020	R.4	950	...	...	...	...	...	...
,,	,,	,,	F.5	403	560	157	259	173	3600	26·012
,,	,,	,,	F.6	165	335	170	437	162	3600	27·300
,,	,,	,,	F.7	47	228	181	635	90	3800	36·311
,,	,,	,,	F.8	9980	148	168	1031	146	5000	26·787
,,	,,	,,	F.9	9960	103	143	1433	203	4700	27·484
,,	,,	,,	F.10	5	083	78	1867	263	1800	27·470

The characteristics of the finishing-mill motors confines the tandem mill to certain maximum and minimum speeds on different gauges, and a typical example of mill settings is given in Table VI. Figure 9 shows the speed cone for the Abbey mills and the dotted lines represent the range which would in the light of experience be preferred to give

(i) Higher finishing speeds to produce uniform gauge and greater rolling rates on lighter gauges, and
(ii) Lower speeds in the bottom range for greater flexibility.

The difference in time that the front end of the strip takes to pass through the rolls after the slab has left the furnaces causes a proportionate variation in temperature and by this means also in gauge. It is therefore advantageous to operate at the highest possible rolling speed. Various attempts have been made to reduce this difference in gauge between front and back, and the devices tried are pre-set screwdown control on the finishing mills and water sprays with a tapering control ahead of No. 5 stand for cooling the front end of the strip relative to the back; automatic control of gauge by roll setting, using a loadmeter coupled to the screwdowns, is also receiving consideration. At Abbey it has been found that by running up No. 4 mill to increase the thickness and capacity for holding heat the difference in gauge between front and back can be considerably improved.

There is an urgent need for a fully automatic method of gauge control, and the introduction of loadmeters[8] into mills for measuring roll force is yielding considerable data. Whilst X-ray meters (Fig. 10) are at present used for the continuous measurement of gauge, current experiments with loadmeters measuring roll-separating force, may enable screwdowns to be automatically adjusted to correct gauge by this aid. Width meters located after No. 4 mill and after No. 10 mill afford greater control of width and enable side scrap from supplementary processes to be reduced.

Finishing and coiling temperatures are of vital importance to the final physical properties of the sheet; whilst finishing temperatures of 1650° F offer no difficulty except on light gauges at reduced finishing speeds, coiling temperatures below 1200° F provide a problem when the mill is rolling in excess of 1800 ft/min. The Abbey hot strip mill is no exception to the common complaint of insufficient water, and the overhead sprays using 9000 gal/min at 80 lb/in², together with 1500 gal at 40 lb/in² from bottom sprays, are not adequate for cooling certain gauges at optimum speeds. High-pressure overhead sprays offer an obstruction to the strip passing along the run-out table at high speed where the rollers are pitched as far apart as 24 in. The table should be designed with 18-in. pitch rollers, as in the case of the high-production mills in the U.S.A., permitting uniform cooling from front to back using approximately 12,000 gal/min applied equally to the underside and overhead at a pressure not necessarily greater than 40 lb/in². The distance of the coilers from No. 10 stand determines the effect of air-cooling and has therefore a considerable influence on the amount of cooling water required. For this reason, and for holding strip in the event of coiler troubles, it is preferable that this distance should not be less than 400 ft.

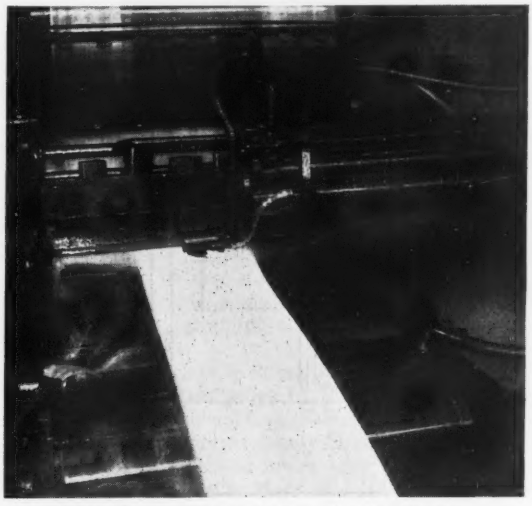


Fig. 10—X-ray head after No. 10 stand

COILING

The mandrel-type coiler (Fig. 11), which is designed essentially to give a uniform, tight coil, obtains the initial wrap from four pairs of retractable wrapper rolls. The coiler presents one of the most difficult maintenance problems in a wide mill and therefore offers the greatest hazard to production. It is preceded by a pair of pinch rolls and the strip enters at speeds of up to 2000 ft/min, producing a heavy impact on the pinch roll and coiler assemblies. For the sake of simplification, the original idle bottom rolls were replaced by plates. This proved successful in operation but the coiler was less flexible when the top remaining wrapper rolls suffered damage or breakdown. The plates were therefore taken out and driven rolls inserted. Whilst this design is the best so far produced for wide strip, it cannot be said that it is ideal from an engineering point of view. Automatic adjustment of the pinch roll and mandrel–wrapper roll gaps for different gauges (0·049–0·375 in.) is essential to reduce impact. Shock absorption and quick response of retraction is obtained using air–hydraulic cylinders which have now replaced the original compressed-air design. The mandrel has the link method of collapse and expansion and each is taken out of service every three months (200,000 tons) for overhaul. For outputs of over 35,000 tons per week, two coilers and one spare are essential.

With sufficient heating capacity and reasonable schedules, a modern 80-in. strip mill can produce in excess of 50,000 tons per week.

PICKLE LINE

The items of equipment which comprise a continuous pickling line are: entry conveyor, processor, shears, welder, flash trimmer, stitcher, looping pit, 3–5 acid tanks, wash tank, drier, side trimmer, shears, oiler, and up-coiler.

The rate of pickling depends upon the penetration and thickness of oxide on the strip and the efficiency

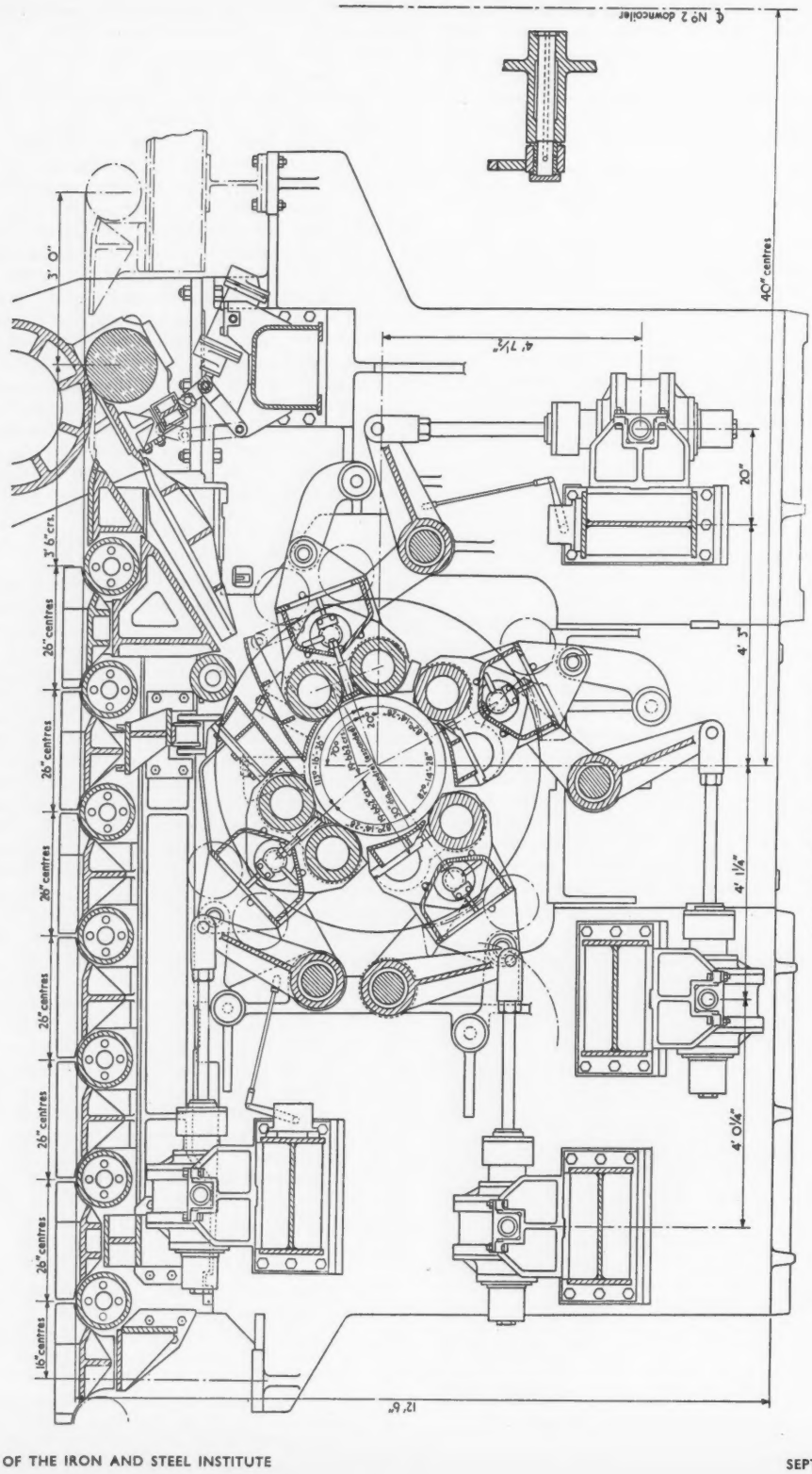


Fig. 11—Section through hot strip mill coiler

Table VII

3-STAND MILL

Mill Drives	No. 1 Stand	No. 2 Stand	No. 3 Stand	Reel
Double-armature d.c. force-ventilated motor	1	1	1	1
R.M.S. output (total for 2 armatures), h.p.	0/4000/4000	0/4000/4000	0/4000/4000	0/1000/1000
Speed range (by armature voltage reg.), rev/min	0/85	0/142	0/170	0/100
Speed range (by motor field weakening), rev/min	85/221	142/300	170/370	100/360
Armature voltage (per armature), V	0/620	0/620	0/620	0/260
Torque: R.M.S. output (base speed), lb.ft	247,000	148,000	124,000	52,500
Working peak, lb.ft	494,000	296,000	248,000	105,000
Cut-out, lb.ft	616,000	370,000	310,000	
Current at R.M.S. output, A	2600	2550	2630	1600
Working peak, A	5200	5100	5260	3200
Cut-out, A	6500	6370	6570	
Overloads	25% for 2 h, 100% for 15 s	25% for 2 h, 100% for 15 s	25% for 2 h, 100% for 15 s	25% for 2 h, 100% for 15 s
	Total Connected Horsepower, 13,000			

of the scale-breaking device at the entry end of the line. Provided that the scale is light and well broken, and with acid concentrations in the four tanks of approximately 22%, 20%, 18%, and 12% at 200° F respectively, tank speeds up to 600 ft/min are possible, giving production figures of 1000 tons/shift. The maximum capacity of the line is a function of the movement of strip through the tanks, and so a well balanced line incorporates sufficient looping-pit capacity ahead of the tanks to provide compensation for the time lost during shearing, welding, trimming, or stitching. Compensation is obtained by running the entry units faster than the line speed, i.e. 1250 ft/min against 650 ft/min. The required storage by the looping pit to sustain continuity of pickling is obviously related to the time lost by the preparation units, the ratio of the speeds, and the distance between each weld or stitch. Coil weights per inch of width must therefore be an optimum, and where this value is too small it may be advantageous to include an additional looping pit in a second strategic location and/or prepare the tail end of each coil using shears at the head of the entry conveyor. The nominal capacity of a single line may be further augmented by obtaining optimum coil weights using a pre-preparation unit.

The advantage of building up coil weights by welding is somewhat tempered by the hazard of passing a defective weld through a high-speed cold-reduction mill; the welder operator may be also over-zealous to the extent of using so much time as to empty the looping pit and lose production.

The homogeneity of the weld is influenced by uniformity of gauge, coil to coil, and across the strip also by freedom of lamination in the strip. Excessive lamination or off-gauge has to be cut out and results in further lost time and lower yields. The welding machine must be of sound construction and requires careful maintenance, and the beryllium copper dies must be changed each week and carefully set when replaced. The upset when welding for gauges within the range rolled at Abbey should be approximately $\frac{3}{16}$ in., and the point at which the current is cut off, particularly on the thinner gauges, is of critical importance to the strength of the weld. Annealing of the weld may have advantages but introduces further interruption to the continuity of pickling.

Table VIII

ROLL CHANGES

	No. 1 Stand	No. 2 Stand	No. 3 Stand
Back-up rolls:			
Crowns	6 top and bottom	6 top and bottom	3 top and bottom
Changes	Every two weeks	Every two weeks	Every week
Work rolls*:			
Crowns	3 top and bottom	3 top and bottom	Par. top and bottom
Changes	Every 1500 tons	Every 1000 tons	Every 400 tons

* These fixed tonnages only apply so long as the finished surface comes up to the finished shape and surface required by the customers' requirements, otherwise rolls must be changed to meet those requirements.

Table IX

REDUCTIONS AND SPEEDS ON 3-STAND MILL

60, 66, and 73 in. wide rimming and stabilized steels

Grade	Width, in.	No. 1 Stand				No. 2 Stand				No. 3 Stand				Total Reduction
		Mill Speed, ft/min	Ingoing Gauge	Outgoing Gauge	Reduction, %	Mill Speed, ft/min	Ingoing Gauge	Outgoing Gauge	Reduction, %	Mill Speed, ft/min	Ingoing Gauge	Outgoing Gauge	Reduction, %	
Rimming	73	620	100	063	37	900 900	064	043	32	1000	043	039	9	61
	73	600	093	060	35·5	900 900	060	040	33	1000	040	036	10	61·5
Stabilized	73	670	084	056	33	900	056	042	25	970	042	039	7	53·5
	73	640	084	055	34·5	900	055	039	29	980	039	036	8	54·75
Rimming	66	840	093	062	33	1200	062	043	31	1320	043	039	9·5	58·0
	66	800	093	060	35·5	1200	060	040	33	1330	040	036	10	61·5
Stabilized	66	750	082	056	32	1000	056	043	24	1070	043	040	7	51·0
	66	720	082	054	34	1000	054	039	28	1080	039	036	8	56·0
Rimming	60	950	093	063	32	1400	063	043	32	1500	043	040	7	57
	60	1000	093	060	35	1400	060	040	33	1520	040	036	10	61
Stabilized	60	890	082	056	33	1200	056	042	25	1280	042	039	7·5	52·5
	60	900	082	055	34·5	1200	055	039	29	1300	039	036	8	56·0

Note: The motor loads on these settings are near their maximum from 70 in. and 73 in. wide, decreasing as the width decreases.

No. 2 line at Abbey will have a magnetic device situated under the tanks in place of the 'dancer' roll for controlling the speed of the pinch rolls at either end. Edge trimmers are provided at the outgoing end to ensure uniformity of width and edge of strip for the cold mill. The maximum diameter of coil is 72 in. and the maximum weight of coil which can be built up has been fixed at 57,000 lb.

Up to the present time, and contrary to what might be expected, the acid tanks, etc., have offered no maintenance problems. However, covers corrode and so fibre glass is being tried in place of steel and rubber.

Steam consumption is too high at 160 lb/ton and carbon heat exchangers are being tried in place of the existing open steam jet for heating the tanks. Acid consumption is approximately 39 lb/ton.

The acid neutralizing plant is only a means of disposing of waste pickle liquor and has no influence on outputs. A pilot plant for the recovery of sulphuric acid is at present under construction using a new process covered by a provisional patent 27,551/52.

There is little doubt that the potential output of a well equipped continuous pickle line is within the region of 20,000 tons per week, depending upon the average width and quality of strip handled.

80-in. 3-STAND COLD-REDUCTION MILLS (TABLE VII)

The pickle line and cold mill schedule follows the same principles as for the hot strip mill, avoiding violent changes of section and, because of roll wear, confining the total tonnage between roll changes to 3000 tons.

Change of width necessitates manual alteration of the sticker boxes and therefore a large number of small items on the schedule is disastrous to high outputs and efficient scheduling of both the pickle line and the cold mill can only be obtained by having a large stock of coils ahead of the pickle line. Bearing in mind that much of this stock is cooling after hot rolling, a minimum of 8000 tons is essential to maximum utilization when producing in excess of 10,000 tons per week.

Weight and quality of the hot band is the foundation upon which high outputs from a cold-reduction mill are built. Uniform width and gauge, freedom from pickling and surface defects, freedom from lamination, and sound welds all promote the confidence of the operator to use the full speed and connected horsepower at his command.

Gauge variation from a tandem cold-reduction mill at constant speed will occur and is due in particular to changes in thickness and hardness of the ingoing strip and to tension applied to it. Tensiometers are provided between stands which indicate the tension in pounds to the operator, who adjusts this to a value between 20,000 and 70,000 lb, according to width and gauge. Reel tension is varied between 3000 and 15,000 lb. Voltage regulators in the electrical control circuit co-ordinate the current requirements of the mill motors during overall speed change and ensure obedience to the pre-set tensions and loads. In spite of this regulator, speed effect persists and off-gauge results.[9]

As it is not yet possible to obtain constant gauge throughout the length of large coils from a hot strip mill and as there are practical difficulties against adapting gauge control to wide hot-strip rolling, it is therefore incumbent on the cold mill to adopt a system of automatic gauge control, the most promising of which has been developed by B.I.S.R.A.[8] It is intended at Abbey to experiment with automatic gauge control for the 3-stand using loadmeters and by means of a radiation meter either before or after No. 1 mill signalling to the screwdown of this stand in an attempt to present uniform gauge to No. 2 mill. The many other hurdles in front of perfect gauge control which must be finally cleared are well understood and the highest of these will probably prove to be corrections for shape which are co-essential and

interdependent with those for gauge when rolling wide strip.

Roll crowns used at Abbey are shown together with roll changes in Table VIII. The finishing-stand forged-steel work rolls are changed approximately every 300 tons to preserve the effect of the shot-blast roughness which reduces the chance of the sheets or coils later sticking in the annealing process. Re-hardening of work rolls prolongs their overall life and where temper mill rolls are smaller in diameter (i.e. 21-in. 3-stand, 20-in. temper mill), they can be transferred with further gain in life. This point should be remembered in the design of related mills. Sleeved back-up rolls, using either a forged-steel or cast-steel arbor, offer economies over the use of only solid rolls.

Producing good shape over a range of widths calls for judicious use of roll crowns and application of roll coolant (Fig. 12) in controlling the heat generated from rolling friction and plastic deformation. Roll coolant can be a solution of either mineral or vegetable oil in water. The solution in use at Abbey is mineral oil and water, and it has been found ineffective to increase this concentration much above $1\frac{1}{2}\%$. The volume of solution in circulation is approx. 1200 gal/min with an 8° F rise in temperature. The Steel Company of Wales is supporting further research[10] into the problems of rolling friction and lubrication which is of particular importance to faster rolling speeds of up to 7000 ft/min from 5-stand mills, which universally use palm oil or palm substitute. The retention of good lubricating ability to high temperatures in cold-rolling may be an important reason why palm oil predominates on 5-stand high-speed cold-reduction mills[11]

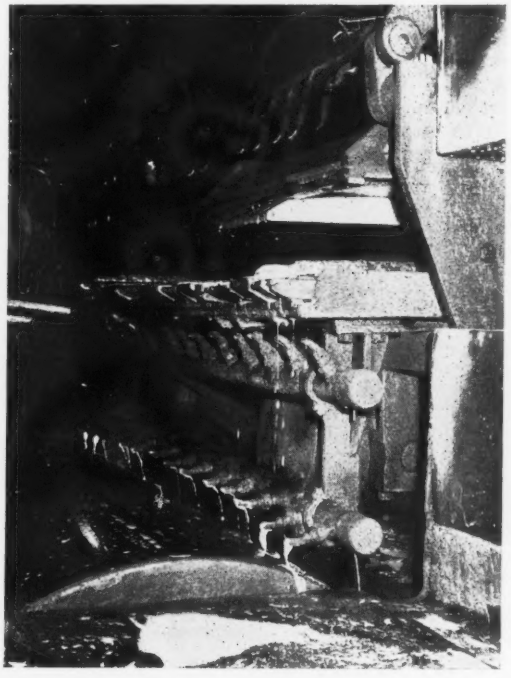


Fig. 12—Roll coolant sprays (3-stand cold-reduction mill)

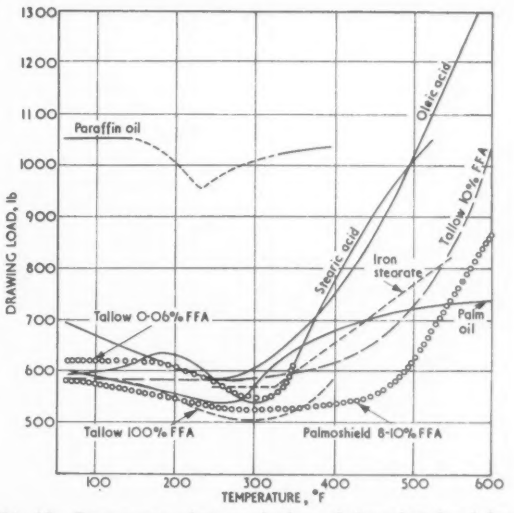


Fig. 13—Summary plot: variation of drawing load for various lubricants (0·207-in. annealed mild-steel rod, 0·184-in. carbide die). From Johnson, Sheehan, and Schwartzbart[11]

(Fig. 13). The 4-stand mill running at 3500 ft/min is in rather a dilemma, seemingly midway between mineral oil and vegetable oil. Table IX gives typical mill settings and loads rolling wide strip. The question of what proportion of the total elongation from slab to cold strip the cold mill should perform has apparently settled itself outside of any carefully calculated economical considerations and evolves from:

(i) The plastic behaviour of hot strip under the influence of successive roll deflections becoming more difficult to control per unit of width as the rolling loads increase

(ii) The effect on grain structure of varying amounts of cold work in relation to annealing temperatures.

Metallurgically, the ideal proportion of cold reduction for sheets of extra-deep-drawing quality rimming steel is approximately 45–50%, but as it is impracticable to roll strip over 65 in. wide to gauges much less than 0·090 in. on an 80-in. hot strip mill, even on one as robust as the Abbey mill, this ideal is exceeded for certain cold sheet gauges. Unfortunately, the wider sheets for automobile roofs, bonnets, etc., represent some of the most exacting draws; and it may be open to question therefore whether the work rolls and back-up rolls or even the housings of the last stands of the modern hot strip mills are of sufficient rigidity. Without doubt, there is great scope for research into the plastic behaviour of metals in the roll gap, and it will assume greater urgency if the present trend of lighter gauges for motor-car sheets is universally adopted.

ANNEALING

Continuous annealing has only progressed for tinplate and for narrow strip manufacture. Wide sheet for press work, etc., continues to be annealed by the ' box ' method, either as sheet or as coil. There are

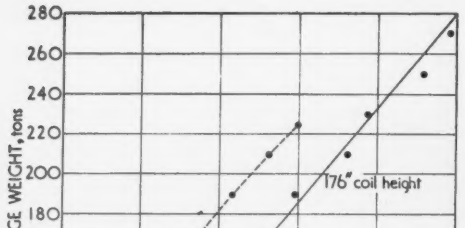


Fig. 14—Annealing output per hour related to load

certain applications of sheets to press work which produce the best results from sheet annealing but, excluding these and certain small orders, it is more economic to anneal as coil. The diameter of coils decides the width of furnace. The permissible height of stacking one coil on the other related to the diameter determines, together with the number of stacks, the load which can be carried on each base; this was mentioned earlier in the compounding of ingots and slabs to show how necessary it is to have each coil as near to the maximum diameter as possible. It then becomes a matter of interpositioning the large variety of widths to take up the full stacking height and for which outputs of over 9000 tons per week demand a selective coil stock of not less than 5000 tons.

The original coil furnaces allowed only 144-in. stacking height which, owing to the fortuitous variation of widths on the order book, it was rarely possible to utilize. It was decided therefore that new installations should have a maximum stacking of 176 in. to

Fig. 15—View of annealing furnace showing burners

provide greater loading and thereby increased annealing rates per furnace. Figure 14 shows the tons/h related to weight of charge for the 144-in. and 176-in. bases respectively.

In most coil-annealing furnaces for wide sheet, the horsepower of the base fan has been established at 15. At Abbey it has been found that the load for the first half hour of heating requires 17 h.p., after which it falls away to 8 h.p., where it remains constant

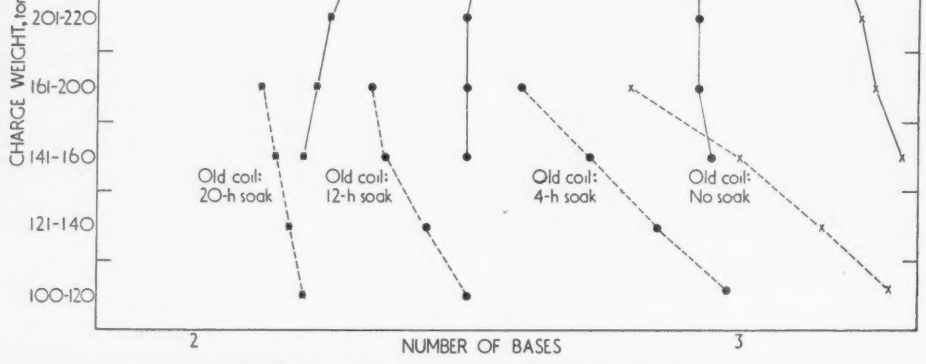


Fig. 16—Number of annealing bases per furnace

during heating and soaking. The volume of H.N.X. gas circulating is approximately 6500 ft³/min per fan. The use of convector plates between each coil increases the efficiency of the furnace, but it is not known whether fans requiring more than 17 h.p. would offer further advantages.

The proportionate number of bases needed to provide maximum utilization of each furnace is related to the heating plus soaking plus cooling times and the time spent in loading or discharging the bases. The heating is a function of the design of the furnace, particularly the method of transmitting heat. The burner for coke-oven gas used at Abbey is in the form of an open bowl (Fig. 15) emitting an open flame and constructed from heat-resisting steel normally operating at 1600° F. The difference between the bottom and top temperatures of the coil stacks is approximately 60° F both for the 144-in. and 176-in. furnaces, and the average B.t.u.'s consumed per ton are 950,000 for 144-in. and 880,000 for 176-in. furnaces. The soaking time is a variable (i.e. 4 h, 12 h, 20 h, etc.) and is related to the severity of the draw to which the sheet will be subjected and to the grade of steel. To obtain the optimum rate of cooling which will balance the other factors in establishing the number of bases required, forcing methods are necessary using either air fans or a water-cooling hood. The possibility of refrigerating the deoxidizing gas has been considered. Figure 16 shows the number of bases per furnace related to soak time plotted against charged weights for both 144-in. and 176-in. furnaces.

The original gas generators circulating N.X. gas through the inner covers have been discarded in favour of nitrogen obtained as a by-product from a nearby oxygen plant. About 3% of hydrogen is added for eliminating traces of oxygen and the dew point is controlled at − 30° F. Purge times are 2 h. A comparison for colour greatly favours the H.N.X. gas.

Inner covers at Abbey were originally of 25/12 Cr–Ni alloy, and for coil-annealing this metal has proved extremely satisfactory. The present condition of these covers suggests that their lives will be indefinite. Covers for sheet-annealing in 25/12 Cr–Ni alloy became embrittled with age, and it was found difficult to straighten out the distortion which occurred; trials are therefore being made using 18/8 Cr–Ni alloy, and also with mild steel. At present the mild-steel cover is very satisfactory and it may be that the life obtained will, in relation to the original cost, give a better performance than the alloy-steel covers. The cost ratio of the mild steel to the alloy steel is about 1 : 5.

The enormous capital outlay in the form of floor space and building required for box-annealing should encourage greater research work into continuous annealing with the object of extending this method, now in use for tinplate, to certain grades of sheet.

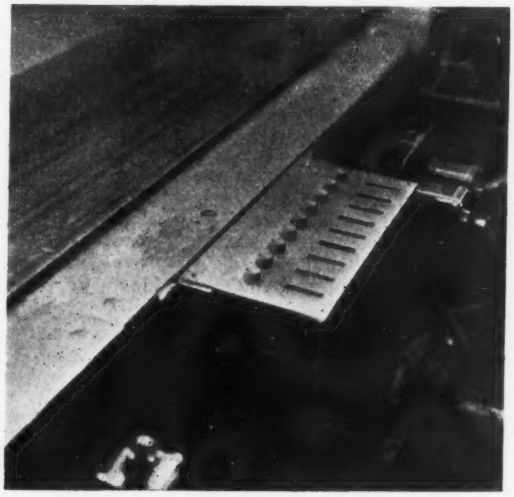


Fig. 17—Cut-up line: inspection counting device

TEMPER PASSING

The output of a coil temper mill is not particularly influenced by scheduling and it is therefore economic to cool the waiting coils or sheets as rapidly as possible to avoid excessive stock. Throughput depends on large coils and avoidance of damaged coil edges caused by wandering on the reel of the 3-stand mill and later becoming flattened (by stacking in coil anneal).

Various methods are in use, including a magnetic device[12] as at Abbey for measuring the small reduction in gauge this mill has to perform. None of these have yet been able to inspire sufficient confidence to be able to dispense with direct measurement by scribing. The latter is in itself rather inaccurate, being carried out at thread speed, and does not therefore account for change in gauge due to change in speed or to change of friction in the roll gap caused by wear of the shot-blast pattern.

The final surface of the sheet required by the customer as measured on a Talysurf meter is obtained by shot-blasting the surface of the work rolls of the temper mill. The grade of shot used is 24 (angular) applied at 30 lb/in². Work rolls are changed according to shape of material and wear of the shot-blast pattern. Whilst it has been proved on a laboratory scale that small rough rolls are more effective in suppressing the yield point than the larger rolls of the present orthodox temper mill, there are obvious practical difficulties against the adoption of this.

The temper mill represents the final process to customers having their own decoiling and shearing blanking equipment, and for their needs coating oil is applied between the mill and the reel.

CUT-UP LINES

A modern high-speed sheet-shearing line comprises pay-off reel, pinch rolls, side trimmer, looping pit, leveller and end shears (reciprocating or drum type), pass-out conveyor, leveller, inspection table, rejection shute, prime conveyor passing over reject piler, retractable oiling machine, prime piler, weighing machine, and run-out conveyor. The length of the line from reel to end of final conveyor is as much as 285 ft.

Large coils and acceptance of heavy bundles by customers are essential to high outputs from shearing

lines. However, there is a very wide difference between the slowest lines in operation at 150 ft/min and the fastest at 1000 ft/min. In the slower lines the reciprocating shear is the limiting factor, whereas in the fastest lines, using a rotary shear, pilers are the restriction. The mechanical efficiency of the reciprocating shears is very low and suffers early from fatigue. It is essential to the continuity of the line that a complete spare shears is on hand. All high-speed lines use shingling equipment and in one or two cases have more than one piler, to avoid as far as possible stopping the line to change small-weight packs.

Side trimming can be carried out either at the pickle line or at the cut-up line, or at both. The most lucrative course is for the hot mill to work as close to the specified width as possible and, assuming a good rolled edge, to remove the predetermined minimum side scrap at the pickle line. The density of the scrap returned to the melting shop is greater, the cold mill is presented with uniform edge and width, the annealing furnaces are not processing a percentage of scrap, and the output of the cut-up lines is considerably improved.

In dealing with a large number of small items having similar gauge but slight variation in width and length, it becomes a balance of process capacity whether to weld together on the basis of common gauge to provide large coils for the cold mill and annealing and accept interruption of the cut-up lines to change sheet length and width, or whether to process small coils throughout all units. The former also causes a slight extra loss of side scrap.

A cut-up line represents the first stage of inspection and a rejection piler is included. Sheets rejected for either off-gauge or surface defects enter a trap operated automatically or by the inspector using press buttons. On one of the Abbey lines a device has been installed (Fig. 17) which counts under classified rejects. Gauge is indicated from a contact flying micrometer and this or a radiation gauge should be fitted with a recorder to provide statistical information on the accuracy of rolling.

DESPATCHING

Prompt despatch is essential not only for the sake of good organization but also in view of the phenomenon of ageing of tempered rimming-steel sheets. The despatch bay should be divided into areas representing the largest customers, such as press shops, etc., where the loads can be quickly located and identified as soon as road transport arrives. With rail transport it is advantageous to trumpet sheets and to wedge them in position carefully so that damage does not occur during shunting.

Handling by crane provides a slinging problem when handling wide sheets, and no alternative fast method has yet been evolved to the use of ordinary flat wire slings. Sheet carriers suspended from the cranes are difficult to manipulate on to lorries or into rail wagons and in any case are slow. All the care taken to roll good shape and good surface finish can be destroyed by bad stacking and by allowing the seal of the band to rest between the surfaces of sheets. In the handling of coils between units it is fatal so far as quality is concerned to allow these to roll on a ramp or to slide on a gravity roller conveyor.

PLATES AND HOT-ROLLED SHEETS

The processing of plates and hot-rolled sheets after hot-rolling is in many respects similar to that discussed above. However, this paper should not close without comment on the high quality of plate produced from continuous 4-high mills compared with the orthodox 2-high or 3-high plate mills. The surface condition due to the efficiency of descaling and frequent roll changes, together with the uniformity of gauge resulting from the rigidity of the mill stands, produce plates well above the average plate produced from the orthodox 2-high plate mills in the U.K. The development of coiling thick gauges (i.e. $\frac{3}{8}$ in.) allows a high rolling rate for plates to be achieved, although this is somewhat lower for gauges over $\frac{3}{8}$ in., which are rolled in lengths up to 200 ft on to cooling banks. A continuous plate-mill reversing roughing mill serving four finishing stands should be capable of producing 22,000 tons/week of plates for a favourable order book.

References

1. *Iron Coal Trades Rev.*, Special Issue, Jan., 1952.
2. R. H. SLADE: *J. Iron Steel Inst.*, 1956, vol. 182, pp. 3–9.
3. R. W. BERRY: *Iron Coal Trades Rev.*, 1953, vol. 167, pp. 887–892.
4. G. S. MICAN: *Iron Steel Eng.*, 1954, vol. 41, No. 5, pp. 55–71.
5. J. I. T. GREEN and A. CONWAY: *J. Iron Steel Inst.*, 1955, vol. 180, pp. 34–38.
6. H. H. ASCOUGH and T. JONES: *Iron Coal Trades Rev.*, 1954, vol. 168, pp. 445–450.
7. S. E. GRAEFF: *Ibid.*, 1952, vol. 165, pp. 53–57.
8. R. B. SIMS and K. H. SLACK: *Proc. Inst. Mech. Eng.*, 1955, vol. 169, pp. 255–268.
9. R. B. SIMS and D. F. ARTHUR: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 285–295.
10. P. W. WHITTON and H. FORD: *Proc. Inst. Mech. Eng.* 1955 vol. 169, pp. 123–140.
11. W. R. JOHNSON, J. P. SHEEHAN, and H. SCHWARTZBART: *Blast Furn. Steel Plant*, 1953, vol. 43, No. 4, pp. 415–423.

DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

Autumn General Meeting, 1955

THE AUTUMN GENERAL MEETING OF THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 16th and 17th November, 1955, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Sir Charles Bruce-Gardner, BT., occupied the Chair on the first day. On the second day, in his unavoidable absence the Chair was taken by the Hon. R. G. Lyttelton, Past-President, except during the discussion of the papers by R. E. Lismer and F. B. Pickering at the morning session, when the Chair was taken by Dr. C. A. Edwards, F.R.S.

DISCUSSION ON THE FURNACE SCANNING PERISCOPE

This discussion was based on the paper by Mr. C. Burns (Instruments Section of the B.I.S.R.A. Physics Department) entitled **"A Furnace Scanning Periscope,"** which appeared in the July, 1955, issue of the *Journal* (vol. 180, pp. 241–247). Mr. Burns presented his paper, and showed a film illustrating the potentialities of the new periscope.

Mr. **Burns:** When the paper on the B.I.S.R.A. Furnace Scanning Periscope was put down on the programme for this meeting, we in B.I.S.R.A. were preparing to make a short information film on the same subject, so we speeded up its production, and are able to screen it to the meeting today, in substantially the form in which it will be used in the future. If a few refinements are missing, we beg you to allow for our inexperience as film-makers. The subject is however primarily one for the eye, and the film can show things which no amount of talk can convey.

With a brief but grateful acknowledgment, therefore, of the efforts of the Information Section, the Drawing Office, and the Photographic Section of B.I.S.R.A., who joined with the Physics Department in producing this film, I should like straightway to present to you, "Operation Shadrach."

[*The film, which will be issued under this title, was then shown with recorded commentary.*]

Mr. **J. W. Till** (John Summers and Sons Ltd.): The instrument which Mr. Burns has described was designed primarily for scanning the roof of an O.H. furnace from a position through the back wall. The value of the instrument has been increased by the fact that it has been possible to use it successfully for observation of the flame through the front and end walls, as well as for its original purpose.

Our experience with the instrument at John Summers has been mainly from the end of the furnace; in this position, observation of flame development and flame application to the charge may be undertaken. We have made several studies of these flames, both visually and with the aid of a cine-film, and the results have been very encouraging. The shots in Mr. Burns' film, though quite good, are not so clear as the actual view through the instrument. The differences observed are not always easy to interpret, but we expect the periscope to provide a means for studying the effect upon the flame of slight adjustments in burner position, inclination, and of atomizing conditions.

During the last few years much work has been done, by means of models, on the examination of the flow patterns inside O.H. furnaces; it is hoped that the periscope will provide a means for observing on a full-scale furnace the results of changes suggested by model work, changes occurring in flame development, and in flow lines of the gases resulting from modifications made following the model changes.

In certain periods during the charge, there is a very heavy carry-over of slag, particularly with hot metal; this carry-over causes rapid wear on the furnace ends. The periscope has been set up at John Summers in the end wall, so that the dripping from the end wall passed across the field of view. We tried to get a quantitative value of the amount of wear on the end wall by counting the drips per minute. The material that drips down approximates to the composition of slag, and it is reasonable to assume that the dripping is closely associated with the rate of wear. A number of casts have been followed on lines such as this, counting the drips and associating this number with the time, condition, and the operation of the furnace, and we are certain that the severity of wear may be seen to increase with an increase in hot-metal percentage and with tar fuel compared with oil fuel; it has also been seen that the rate of wear increased rapidly if the reversal sequence was prolonged. If the furnace is not reversed at the proper time, the rate

of drips per minute rises rapidly with the longer period: so much so that we have instituted a shorter reversal time, made it automatic, and markedly reduced the rate of wear on the furnace end.

The wear on the main roof has not been observed in this way but it would seem reasonable to expect that, if a hole were available in the back wall, the periscope could be sited on a particular area of the roof, and the dripping observed, where it is known that wear is localized.

Mr. Burns has provided an instrument that should help to increase knowledge of flame application in the furnace. It only remains for him to reduce the size of the instrument to the minimum, to make the instrument more easily handled.

Mr. **Burns** (in reply): On the last point, I can add a reassuring postscript to Mr. Till's remarks. We have given much thought to reducing the size and weight of the periscope for commercial production without prejudicing its optical performance. The production model, which will soon be seen, is a considerable improvement over the prototype in this respect.

Mr. Till's tests and our other trials have provided much experience in the melting shop, which has been valuable in designing a commercial model. I am glad Mr. Till has adduced some practical experiences with the periscope to show that, even in prototype form, it has provided informative observations and some concrete results.

The **President:** A periscope of this nature is a very useful adjunct, in that it enables the practical men on the site to see the exact effect inside the furnace of the various alterations that may be made to the shape of the furnace, its intake and exit, and to the burner. It is a tremendous advancement in the practical life of the furnace to be able to see rapidly the effect of alterations instead of having to deduce afterwards whether the amount of wear has been lessened or increased. The maintenance of the furnace and the time it can be run before having to be taken out are as important as the time taken to get the heat out. All furnace managers are striving to increase the period of productiviy and an instrument of this type will be a great help.

Mr. **J. Monaghan** (Union Carbide and Carbon Company): Could the instrument be made slimmer, so that it could be put through the tuyere of a blast-furnace?

Mr. **Burns** (in reply): It could probably be done, but it would require a completely redesigned instrument. The periscope at present is 6 ft long overall and about $4\frac{5}{8}$ in. outside diameter; we hope to cut this down to about 4 in. The length is almost immaterial from the operator's point of view, because only a few inches of the periscope nose emerge from the refractory and most of the cooling is required there. There is usually a good margin, and the rise in temperature of the water while operating in the O.H. furnace is only about 10° C.

The problem on a blast-furnace tuyere is somewhat different, because the tube would be exposed through most of its length to a blast of hot air and at its nose to a radiation comparable in intensity with that in the open-hearth. At the same time, one might reduce the diameter by changing the optical design, and that would also depend on the performance required of it.

Therefore, although I would not like to commit myself, I should say that a workable instrument of this nature might be produced if a research demand arose for it. In this connection, I should like to recall the work B.I.S.R.A. has already done with stereoscopic photography, which mapped out accurately everything that could be seen directly down the blast-furnace tuyere. It appears that Mr. Monaghan is now anxious to see round the corner!

Mr. **F. Steghart** (Consulting Engineer): Is it possible to use this instrument indefinitely? It might be very useful in automatic control, but the question arises whether any problem is created by the splashing of hot metal or by the accumulation of dust.

Mr. **Burns** (in reply): Prolonged trials in collaboration with John Summers and Sons have given us a good deal of information on this. The splashing of the windows varies greatly with the siting in the furnace. The back wall is the worst position, because the periscope would stick right out into the stream going down the furnace. The prototype could withstand it for a period varying from a few minutes up to half an hour, depending on the quiescence or liveliness of the bath. The position through a charging door is better, because the charging door itself constitutes a recess and to a certain extent stops direct splashes from reaching the periscope windows. These windows will probably be much better protected in the production model than in the prototype. The end position beside the burner, which we used at John Summers and Sons, is the best, and one can do practically anything with a periscope there. We used it indiscriminately with the burner flame coming from that end and the opposite end, in spite of the smoke that issues from the hole opposite the working burner. At one time we used the periscope for five months—only the forward-looking window being used—and only a slight sooty deposit was left on it; we could have used it for much longer.

There is therefore good hope that, if one chooses the sites carefully, one can make very prolonged investigations of furnace conditions.

The **President:** Coloured photographs will indicate the relative temperatures one against the other, but they will not give the actual temperature. Might it be possible to add a water-cooled visual pyrometer?

Mr. **Burns** (in reply): The suggestion of adding a direct pyrometer in parallel with the periscope might constitute an investigation in itself. It would tie up, even if only qualitatively, the heat distribution of the objects in view with some absolute value. In B.I.S.R.A. we are investigating another line whereby a different periscope with a different optical system permits one to look directly at any portion of the field of view and feeds directly into a photo-electric detector. This also would require calibration from an independent source looking through the periscope optical system.

The periscope has a wide variety of potential applications, and we have so far concentrated on the easier ones, which will give dividends quickly and without prolonged investigations, the success of which might be problematical. However, in the future some of these more difficult investigations may give useful results.

DISCUSSION ON OIL IN OPEN-HEARTH STEELMAKING

This discussion was based on the paper by Dr. C. A. Edwards, F.R.S., entitled **"The Relative Merits of Low- and High-Sulphur Oil for Open-Hearth Steelmaking,"** which appeared in the October, 1955, issue of the *Journal* (vol. 181, pp. 138–147). Dr. Edwards presented his paper.

Dr. **J. Pearson** (B.I.S.R.A.): I suspect that Dr. Edward's paper is really written for steelworks staff, and it is, therefore, a very useful contribution. If I make some criticisms of his paper, I do so only to gain more information.

Dr. Edwards has obviously been worried about the

serious difficulties that high-sulphur fuel causes in O.H. operation, and he has attempted to give these a quantitative basis. By subtracting from the total burden at tapping the sulphur in the materials charged, he has arrived at a series of figures for sulphur pick-up, and the results (given in a Table on p. 141) show notably a linear relationship between sulphur pick-up and the sulphur content of the oil. This confirms what German and French workers have found. When did the sulphur pick-up arise, and what, in addition to the sulphur content of the fuel oil, determined its level? Dr. Edwards shows that, when hot metal high in sulphur is added to a furnace, it does not lose sulphur because it is under slag cover, and one could assume from this that any metal which is under slag will neither lose sulphur to nor gain it from the gases. Practical experience indicates that there is no significant change in the sulphur burden after melt-down. The sulphur pick-ups which Dr. Edwards has given can be taken therefore as occurring during melt-down, and that is precisely what Trentini, Peters, and Husson have said, namely, that they correlate with the total amount of sulphur brought into a furnace by the fuel oil. These authors have shown that during a melting down some 28% of the sulphur in the oil fed to the furnace is absorbed by the charge, and, in a similar experiment carried out by the B.I.S.R.A. staff at Sheffield on a furnace which had about 50% of hot metal in the charge, there was during melt-down a similar pick-up of sulphur from the oil. The sulphur pick-up appears therefore to be directly dependent upon the sulphur content of the oil only if the amount of oil used during melting down is constant; it would be better to regard it as dependent upon the sulphur content of the oil times the amount used. It would be interesting if, from his figures of the working of the furnace, Dr. Edwards could confirm this.

Dr. Edwards claims that a balance is reached between the sulphur absorbed by the scrap and the percentage of sulphur in the fuel oil used. The evidence for this would have been of great interest but we have to be content with the statement that a $\frac{1}{4}$% sulphur-scrap charge had the same sulphur burden at tapping as did those using a normal scrap. Harders, Grewe, and Oelsen showed two or three years ago that such a balance exists, but independent confirmation from Dr. Edwards would have been very valuable. I cannot agree with Dr. Edwards that this balance renders unnecessary a reasonably accurate knowledge of the sulphur content of the scrap; according to the balance, a low-sulphur scrap will pick up more sulphur than a high-sulphur scrap, and one must know the original sulphur content, to be able to determine the amount picked up.

With regard to Dr. Edwards' choice of 10 as the sulphur partition, it is to be noted that he is dealing with steels having a sulphur content of 0·25 and 0·4%, and Table V shows that such steels in practice have values varying between 3 and 14. I realize that the figure 10 is intended as a target, but if you assume a sulphur partition of 10 and then calculate the slag bulk which will be required, the chances are that the slag will not give a sulphur partition of 10. It would have been interesting, therefore, to see how these predictions are borne out in practice.

Dr. Edwards introduces his paper with a discussion of phosphorus distribution, but then makes an arbitrary choice of 10% for the P_2O_5 in the slag. He claims that one set of results is at variance with all the others examined and advances three reasons for this, but he does not indicate why these particular reasons are valid. Dr. Edwards suggests that the physical chemist should attempt, by using the laws of thermodynamics, to bring those discordant results into one group. German, American, and British workers have for years been describing the influence of slag composition on phosphorus distribution, and it is up to the author to see whether their methods of interpreting data will fit his facts before coming forward with new ideas. He would find that, with a less arbitrary basis for the correlation, all the figures can be shown to be of one group.

Dr. Edwards also tends to dismiss too lightly the published work on sulphur distribution and concludes that there is no simple relationship between slag basicity and the sulphur-distribution ratio. That is already known to people who have read the research work on the subject, and to steelmakers, all of whom know that the degree of oxidation is also a very important factor in sulphur distribution. Dr. Edwards has shown that there is a good relationship between sulphur distribution and the basicity versus the residual manganese content; this may be a very important and useful relationship for works operation, but I would point out that it is merely a re-presentation of previous knowledge in a new form. Dr. Edwards says that

$$\frac{(S)}{[S]} = K \times B \times [Mn]$$

He points out that residual manganese is really dependent upon differences in the MnO/FeO ratios in the slag—it is, roughly speaking, a measure of the oxygen potential of the system he is dealing with; and since in general manganese will decrease as the degree of oxidation goes up, we could write

$$\frac{(S)}{[S]}[O] = K'B$$

i.e. the sulphur capacity of the slag is a function of its basicity, a lesson which Dr. Richardson has been preaching for some years; Figure 4 is, therefore, merely another way of representing a well-known relationship. It does not allow the claim that manganese has some magical influence on the removal of sulphur, but merely that at tapping both manganese and sulphur are at or very close to equilibrium.

Dr. **Edwards**: It is difficult to give an adequate reply to the many deeply thought points that Dr. Pearson has made. I would say, however, that I did not intend to suggest that manganese acts in a mysterious way. I think I make it clear, by reference to other people's work, that I believe it to be merely a reflection of the oxygen content of the metal. Therefore, my views in no way conflict with those of Dr. Pearson or of Dr. Richardson. It is merely another way of showing how one can obtain a clear picture of the whole situation by reference to the manganese content of the bath at tapping. I am not surprised that Dr. Pearson raised the question of why I selected 10% P_2O_5. The reason was that I wanted to indicate as far as possible what was the maximum P_2O_5 we might expect to be able to carry under normal practical conditions, and the selection of 10% as the figure indirectly represents the minimum volume of slag.

Dr. **Pearson**: I did not mean to imply that Dr. Edwards was assuming a magical effect for manganese. What I wished to point out was that his paper showed that manganese did not have such an effect.

Mr. **J. W. Till** (John Summers and Sons Ltd.): All steelmakers will be grateful to Dr. Edwards for his paper, particularly those who have to make low-sulphur steel from high-sulphur fuels.

This aspect has been emphasized in the Shotton practice for at least 10 years, and we are pleased to find that Dr. Edwards' work confirms quite a number of our findings, which were originally published under the late

F. L. Robertson's name in the *Transactions* of the A.I.M.M.E. in November, 1951. These results covered about 400 casts and were on an 80-ton cold-metal charge using one type of fuel containing 2·5% of sulphur. Dr. Edwards' work on differing sulphur fuels is interesting because it fits in with our figures, including those obtained later in our new shop, which dealt with hot-metal and mixed-fuel firing.

We are able to confirm Dr. Edwards' first point on p. 138 concerning the P_2O_5 and the SiO_2 content of the slag, namely, that the desired phosphorus in the metal may be the deciding factor for the bulk of slag carried. In our case the desired phosphorus content of the metal is a maximum of 0·15% using 0·75–1% of phosphorus iron; we found that the slag bulk required for the sulphur burden was sufficient to give us a P_2O_5 in our slag of between 4 and 6%. This has been confirmed again on the new shop, when we conducted a trial using Canadian low-sulphur and phosphorus iron in comparison with our normal pig iron from Shelton. This was reported by my chief, Mr. Bacon, in S.M.A.G. 39/53. The phosphorus in the Canadian iron was 0·115% and the sulphur 0·21%; the Shelton iron was 1% phosphorus and the sulphur about 0·35%, yet a lower pit sulphur was obtained with the Shelton iron cast because of the higher lime charged and fed, which was called for by the phosphorus in the iron. Consequently, there was a lower metallic output with the Shelton iron charges. The Canadian iron gave us about 1·6% higher output than the Shelton iron. The total lime charged and fed with the Canadian iron was 90 lb/ton and with the Shelton 150 lb/ton. With 45% lime in the slag, there are six extra tons of lime or 13 extra tons of slag, mainly to deal with the differing phosphorus there and to give us the low sulphur required. The economics of that slag bulk are quite obvious.

With 50% hot-metal charges, we find similar trends to the plots in Fig. 1 on the composition of the slag after hot-metal addition, except that our values, being lower in phosphorus, do not show the same high P_2O_5 figures, but the others, particularly the Fe, show much higher ranges than those of Dr. Edwards; the trends, however, are similar.

I wonder whether Dr. Edwards has any figures for iron in his slag immediately after the addition of hot metal, because we find that our iron content is very high at that point and, if there is a flush-over, the metallic loss can be quite high.

We glanced at group 1 (*c*) in Table I, in line with the formulæ and papers of Quarrell and his associates in 1946 and 1947. It seems that if one uses these formulæ and takes into account the temperature, the calculated figure corresponds well with the phosphorus observed by Dr. Edwards at tapping.

In regard to the section on the effect of the sulphur percentage on different fuels; I should like a little more information on the methods of computing slag weights, and to know whether the lime or manganese effects on the slag weights calculated on the P_2O_5 basis give a reasonable agreement. On the 400-plus charges that we used, we found that the P_2O_5 figures were less consistent than those calculated on lime basicity. This may be due to the fact that our P_2O_5 is much lower than that of Dr. Edwards, but I should like to know how much he allows for the weight of slag-making material picked up from the bottom of the banks, when using the lime basis.

On the question of iron yield, we must know that before we can do calculations on the amount of sulphur in the steel at tapping. If we take the figures at the foot of p. 141 and assume 97% Fe in the scrap (allowing for the other elements and dirt) and 93% Fe in the pig iron, and assume the addition of 10 tons of ore (I do not know whether there were any ore additions to those charges) at 68% Fe, then we arrive at a charge weight of Fe of about 116 tons. From Dr. Edwards' figures we assume an average weight of about 20 tons of slag with about 20% Fe; that gives us about 4 tons of iron in the slag. If we take 4 tons from 116 tons, we have 112 tons, whereas we are producing only 100 tons. Does Dr. Edwards make any allowance for loss of Fe to the atmosphere? We allow 5%, and that, on our Fe balance, would give a yield of 86%. As Dr. Edwards' 100 tons of steel produced is 86% of 116 tons, I should like to have a little more information on this point.

Dr. Pearson has already touched on the balance between the fuel sulphur, the scrap sulphur, and the sulphur absorbed or lost. May I add one more authority to those he has quoted? Herty, in his 1929 paper, gave a Table showing what he called the 'neutral' sulphur in the fuel compared with the percentage of sulphur in the scrap. He showed that, for an 0·3% sulphur scrap, the 'neutral' sulphur was 0·49% in the coal, if using producer gas, 0·51% in oil or tar, and 123 g per 100 ft^3 for coke-oven gas. If the fuel sulphur is higher than this figure, the scrap will absorb sulphur, whereas, if the sulphur in the fuel is lower than that given in the Table, the scrap will lose sulphur to the gas; the farther apart these two figures are, the faster will be the absorption or loss from or to the scrap.

With regard to the amount of sulphur pick-up in lb per 100 tons, we have not many casts available on our hot-metal practice, but those that we have are based on 65% hot metal, and they give figures very near to those quoted by Dr. Edwards; for 1% sulphur tar and coke-oven gas we get a pick-up of 26 lb, as compared with Dr. Edwards' 25 lb, and for 2·5% oil and coke-oven gas we get 78 lb, compared with his 90 lb. That is understandable, because our coke-oven gas is probably of lower sulphur content than the oil fuel, and the average sulphur of the mixed fuel in the furnace is, therefore, probably nearer 2% than 2·5%. We find that our figures confirm those of Dr. Edwards on flush-slag practice in agreeing with his 40% of phosphorus removed in the flush. Dr. Edwards has said that in some of his figures he has not used a flush slag; I should like to know how he would calculate the amount, if he had.

I should like to mention also the partition factor of 10 (S)/[S]; in our earlier work we used 6 (S)/[S] because we found that applicable to our shop, but as I have said before, the partition coefficient is a function of one's own particular practice. It is a function of time, of time charging, and many other details which make one steelworks practice so different from another; but having found the coefficient applicable to the practice, the amount of slag it is necessary to carry becomes a relatively simple calculation. We can, therefore, confirm Dr. Edwards' estimated slag weights and that the relationship between straight slag basicity and (S)/[S] is a very wide and varied one.

Dr. **Edwards**: I will deal with one or two of the points that Mr. Till has raised, but, for the most part, his observations agree with the contents of the paper.

I considered various methods of calculating the slag volume and finally decided to confine my attention to the use of P_2O_5, in view of the fact that we were considering slags containing a much higher percentage of P_2O_5 than Mr. Till's. When the P_2O_5 is low, the potential error greatly increases, especially if it is associated at any given moment with trouble from banks or bottoms, because that disturbs the situation and one does not quite know how much phosphorus is taken up in that way.

I cannot definitely answer Mr. Till's point about loss of iron, but as far as I could gauge from what he said, the yields agree with his experience.

I am very interested in what Mr. Till said about adopting a sulphur-distribution factor of six. I do not know whether Mr. Till could consider the vital facts that are put in the paper, although they are not put in this form; but is it not possible for him to raise that figure without much additional expense? It seems that his low value is largely due to high basicity and very low residual manganese; an excessively high slag basicity must mean a correspondingly high FeO content and therefore a low residual manganese.

Mr. **Till:** I quite agree with Dr. Edwards on the last point and I should stress that six was the figure that we chose on our cold-metal shop. I agree too with his point about high basicity, and the high FeO and low manganese; but our product has a carbon maximum of 0·06% and we have to carry a high FeO. It is true that, on our present shop, we are nearer 8 or above.

Dr. **B. Trentini** (IRSID): The results obtained by Dr. Edwards are very interesting and the figures for variation of slag volume with sulphur content in oil, for a given final sulphur in steel, are striking.

In France we also have difficulties in getting low-sulphur oil for O.H. furnaces. We made a study of the influence of sulphur in fuel oil, and Dr. Pearson has translated the preliminary report. The complete work will be published in the *Revue de Métallurgie*.

There are some differences between Dr. Edwards' work and ours, but the general conclusions are similar.

(1) In Dr. Edwards' work, charges contained 50% hot metal. Our tests were carried out in a non-integrated plant, so we had to use cold charges; the proportion of solid pig iron was only 15%. The sulphur content of the fuel varied in a larger range, from 0·4 to 3·8%. We tried to keep the operating factors constant, in particular the nature and apparent density of scrap, and the amount of lime charged.

Graphs giving the sulphur content in the final steels and final slags show that the very high sulphur contents are found in slags corresponding to the 3·8% sulphur oils; in the refining period, sulphur in slag went up to 0·800%, a figure surprisingly high for a very oxidizing slag.

(2) If the amount of sulphur present in slag and metal when a uniform slag layer covers the bath is plotted as a function of the sulphur in the fuel burned from the beginning of the heat up to that time, we can easily determine the proportion of sulphur picked up from the fuel during that period; we found about 30% of the total sulphur of oil.

The value of this coefficient must depend upon many factors. Did Dr. Edwards determine this coefficient for the type of charges mentioned in the paper?

(3) In our experiments we used steam in the oil burners. It has been proved in other trials that steam gives a more oxidizing atmosphere than the use of air in the burner, and there should, therefore, be a difference in the sulphur picked up by the charge. Has Dr. Edwards any ideas on this?

(4) In Fig. 4 there are some points with very high sulphur ratios: (S)/[S] ranging from 15 to 30, which seem very high for a normal basic O.H. practice. How are they obtained? What is the corresponding average composition of slags?

(5) I agree with Dr. Edwards that there is no close relationship between slag basicity alone and sulphur ratio (S)/[S] and that oxidizing power should also be taken into account, but I am not sure that the use of residual manganese alone is sufficient, because it does not give the bath oxidation unless the activity of MnO and temperature do not vary.

(6) Definition of slag basicity is difficult, as can be seen from the numerous formulæ proposed by many authors; moreover, the oxidizing power of a slag is not always known accurately, and these two reasons might explain the scatter of points we often find in desulphurization studies.

We compared groups of two slags, having the same composition except for sulphur and coming from two different heats (one with low-sulphur oil, the other with high sulphur oil). We found that, if the bath temperature is about the same, the ratio (S)/[S] is also the same in each group.

It might be assumed that we get a state close to equilibrium between slag and metal in the O.H. furnace, as far as sulphur is concerned, and this agrees with the conclusions given by Dr. Turkdogan in a recent paper on sulphur in steelmaking.

Dr. **Edwards:** I was very glad to hear Dr. Trentini say what he did, because I was interested in the paper which he presented and which was translated by Dr. Pearson a short time ago. I do not think I need to deal in any detail with the points he raised, apart from his reference to the high (S)/[S] values in Table V.

He expressed astonishment at the high (S)/[S] values, particularly under low slag basicity conditions. That would tend to confirm the point that I have been trying to stress throughout the paper, namely, that it is not basicity alone which determines the (S)/[S], but the residual Mn as well. You will notice that in those cases the residual Mn in the bath is particularly high.

Dr. Trentini also mentioned the possibility of high MnO in the slag, which is associated of course with the need for a high residual manganese, and asked whether that would in fact be detrimental to the rate of working. That is a very important factor. I do not think it is at all detrimental providing the slag basicity is of the right order. With a very low slag basicity you can carry a high MnO and still get rapid working. It is really the rate of oxygen transfer, and this does not depend alone upon the quantity of FeO in the slag.

CORRESPONDENCE

Mr. **D. J. O. Brandt** (Metallurgical Engineer) wrote: There is perhaps a danger that Dr. Edwards' conclusions regarding the effect of slag basicity on the distribution of sulphur between slag and metal may be a little misleading. From his Table V and from the graph plotted in Fig. 4, Dr. Edwards shows that sulphur partition is apparently unaffected by slag basicity alone; it is only when the basicity is multiplied by the value of the residual manganese that a reasonable correlation between the two is manifest.

But it should be recognized that throughout this paper basicity has been expressed as a *ratio* between 'free' (i.e. non-phosphoric) lime and silica. This method of expressing basicity gives far greater weight to the effect of silica than it does to the effect of phosphorus, and I believe this to be wrong; since both silica and P_2O_5 can form compounds with lime in the basic slag, and since their effects on the lime content are roughly equal, a better and easier method of expressing basicity is simply to add the percentage of silica and P_2O_5 in the slag and subtract this from the lime content, calling this figure the 'excess base' form of basicity. Thus a slag containing 45% CaO, 15% SiO_2, and 5% P_2O_5 will have an 'excess base' basicity of 25, as will also a slag containing, say, 45% CaO, 5% SiO_2, and 15% P_2O_5, whereas the basicities calcu-

lated on the V formula are 2·47 in the first case and 4·29 in the second.

If the figures in Dr. Edwards Table V are re-plotted on this basis, it will be seen that, as Dr. Edwards points out, there is no apparent correlation between (S)/[S] and basicity expressed as $\frac{CaO - 1{\cdot}57\ P_2O_5}{SiO_2}$ in either the low- or high-residual manganese heats; on the other hand, it is evident that a correlation is to be found between (S)/[S] and 'excess base' basicity and that this is particularly well marked in the case of the high residual manganese heats.

Dr. Edwards has reminded us of the importance of manganese in sulphur elimination, which has lately tended to be forgotten, since most British steelmakers have to work with comparatively low-manganese iron. The differences found between British and German results by Turkdogan* in his examination of sulphur partition and basicity, for example, are almost certainly due to the fact that German steelmaking was conducted with high-manganese 'stahleisen,' while the British results are for steels made with low-manganese iron, and not, as suggested by this author, because the German samples were contaminated. In effect, it is both residual manganese and 'excess base' basicity which govern the sulphur partition.

Dr. **P. T. Carter** (Royal Technical College, Glasgow) wrote: Dr. Edwards is to be congratulated on providing a relationship for sulphur distribution which is applicable over a wide range of slag and metal composition. I have found it to agree satisfactorily with slag-metal tapping data obtained in cold-metal practice, although not with corresponding data obtained at melt out. An important aspect of the relationship shown in Fig. 4 is its ease of application, compared with a number of recently proposed formulæ, although one is prompted to ask whether the use of $CaO–1{\cdot}57\ P_2O_5$ (corresponding to $4CaO.P_2O_5$) gave significantly better correlation than $CaO–1{\cdot}18\ P_2O_5$ (corresponding to $3CaO.P_2O_5$). Furthermore, at first sight, the proposed relationship appears to be contrary to currently accepted ideas on sulphur distribution in the basic O.H. furnace, namely, that sulphur distribution depends on both slag basicity and the state of oxygen in accordance with

$$S + O^{--} = S^{--} + O$$

or some closely related equation. A major difficulty in applying such an equation has been the correct assessment of the latter factor, as the oxygen content of the metal appears to be between that calculated from the carbon content of the metal and the iron content of the slag. It is probable that the value used should be that corresponding to the oxygen potential at the slag-metal interface. If slag and metal are in equilibrium with regard to manganese, it should be possible to determine the oxygen potential from the manganese equilibrium, and there is little doubt that high-residual manganese is indicative of a low state of bath oxidation. Strictly, however, [Mn] should be replaced by $[Mn]/(a_{MnO})$ in the abscissa of Fig. 4. The excellent correlation with (S)/[S] obtained by Dr. Edwards, using the former, suggests that some additional compensating factor has not been taken into account. As both FeO and MnO have a desulphurizing effect similar to that of CaO, *when regarded as basic oxides in the slag*, it is believed that this compensating effect is their omission from the factor $\frac{CaO–1{\cdot}57\ P_2O_5}{SiO_2}$ used to express the basicity of the slag.

It is difficult to interpret the apparent anomalous results for phosphorus removal illustrated in Fig. 3, without further details of the heat histories. Could Dr. Edwards indicate whether there was any significant difference in tapping temperature or in fluorspar additions, both of which have an important effect on phosphorus removal?

* E. T. Turkdogan, *J. Iron Steel Inst.*, 1955, vol. 179, pp. 147–154.

AUTHOR'S WRITTEN REPLY

Dr. **Edwards** wrote: In answer to Mr. Brandt's written contribution, the main object of the paper, so far as the distribution of sulphur is concerned, was to emphasize the important influence of residual manganese in this connection. In other words, slag basicity alone is not the only factor.

This is true no matter what particular formula is used for determining the basicity value. It is not suggested that the V value used in the paper definitely represents the way in which SiO_2 and P_2O_5 are associated with CaO in the slag. There is no doubt that the German steelmakers have a decided advantage when using high manganese iron. With hot metal and heavy flushing practice, this can be met by feeding comparatively low-grade manganese ores after flushing.

It was gratifying to have Dr. Carter's contribution and suggestions, because he has done so much work on the sulphur problem. In view of the observations of both Mr. Brandt and Dr. Carter, I will give more detailed attention to the effects of varying kinds of basicity values in conjunction with residual manganese.

With regard to the anomalous results for phosphorus shown in Fig. 3, I must point out that the data were drawn from widely differing sources, and the evidence relating to tapping temperatures and spar additions was incomplete.

In general terms, however, I have a strong feeling that the deciding factor is the rate at which oxygen is transferred from slag to metal. Apart from the depth of bath and the iron oxide in the slag, etc., there are other factors which have a marked influence in this connection, and perhaps the most important is the net effect they have on the viscosity of the slag.

DISCUSSION ON SOLUBILITY OF CARBON AND NITROGEN

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parenthesis):

"The Thermodynamics of Carbon Dissolved in Iron Alloys":

Part I: "The Solubility of Carbon in Iron–Phosphorus, Iron–Silicon, and Iron–Manganese Melts," *by E. T. Turkdogan and L. E. Leake* (1955, vol. 179, January, pp. 39–42).

Part II: "The Influence of Silicon on the Activity Coefficient of Carbon dissolved in Molten Iron," *by E. T. Turkdogan* (1955, vol. 179, January, pp. 43–45).

Part III: "The Solubility of Carbon in Iron–Carbon Melts," *by E. T. Turkdogan and R. A. Hancock* (1955, vol. 179, February, pp. 155–159).

Part IV: "The Solubility of Carbon in Iron–Silicon–Phosphorus Melts," *by E. T. Turkdogan and L. E. Leake* (1955, vol. 180, July, pp. 269–271).

"Solubility of Nitrogen in Alpha Iron," *by J. D. Fast and M. B. Verrijp* (1955, vol. 180, August, pp. 337–343).

"The Effect of Alloying Elements on the Solubility of Nitrogen in Iron":

Part I: "The Solubility of Nitrogen in Pure Iron and in 2·83% Silicon Iron," *by N. S. Corney and E. T. Turkdogan* (Vol. 180, August, pp. 344–348).

Part II: "The Solubility of Nitrogen in Alpha Iron Containing up to 0·051% Vanadium," *by E. T. Turkdogan, S. Ignatowicz, and J. Pearson* (1955, vol. 181, November, pp. 227–231).

The papers were presented by Dr. **E. T. Turkdogan,** Head of the Physical Chemistry Section of the Chemistry Department of B.I.S.R.A., and included the paper by Professor **J. D. Fast** and Mr. **M. B. Verrijp**, as the Dutch authors were not present.

Dr. **F. D. Richardson** (Nuffield Research Group in Extraction Metallurgy): The papers presented to this meeting form an excellent series for discussion. All the measurements reported have been made with skill and thoroughness, and each is a useful contribution to the fundamental chemistry of iron and steel making.

Dr. Turkdogan has compiled various data concerning the effect of alloying elements on the saturation solubility of carbon, and he has added his own new measurements on the effect of phosphorus and sulphur separately, and phosphorus and silicon together. Technologically, these results are useful as they stand. At low concentrations, sulphur, silicon, and phosphorus have very similar effects in suppressing the solubility of carbon per g-atom added. At high concentrations sulphur has more effect than phosphorus, which in turn has more effect than silicon. Phosphorus and silicon together have effects which are roughly additive.

All these are useful results but they do not help very much in the development of the theory of such solutions, because they all have been conducted at a constant carbon activity of unity. It would be more valuable to know how these added elements change the activity of carbon at a constant carbon concentration. It is time that measurements were made in the 1–5 wt-% C range with iron solutions containing silicon, phosphorus, etc.

I question Dr. Turkdogan's calculation of the effect of silicon on carbon in iron at concentrations less than saturation. It is based on the assumption that an empirical relationship which holds for solid Fe–C–Si alloys, but *not* with solid Fe–C–Mn or liquid Fe–C–Cr alloys, holds for liquid Fe–C–Si alloys. It has no more theoretical justification than the simpler assumption that the ratio of the activity coefficients of carbon in the presence and in the absence of any fixed concentration of silicon is the same at low carbon concentrations as at saturation. The latter assumption was made by Professor Chipman when he wanted to estimate the behaviour of Fe–C–Si solutions, and it leads to carbon activities, which, within the likely error limits, are little different from those now calculated by Dr. Turkdogan.

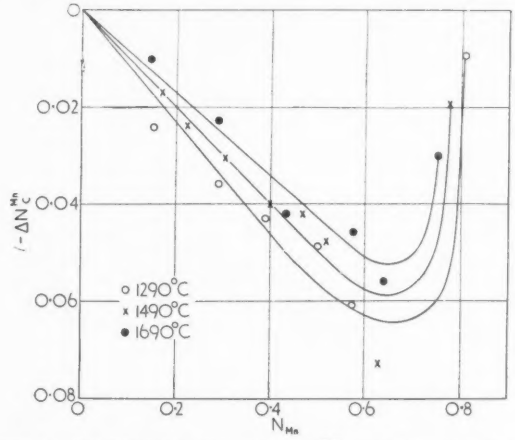


Fig. A—Relationship between $-\Delta N_C^{Mn}$ and atom fraction of Mn, from data of Chipman *et al.*[1]

The papers on the iron–nitrogen system are most interesting, and the work of Professor Fast and Mr. Verrijp adds greatly to our knowledge of the behaviour of nitrogen in α- and γ-iron. This was partly understood before, but some confusion arose when Borelius and Åstrom produced their correction of Dijkstra's results for the solubility of nitrogen in α-iron, in equilibrium with iron nitride. This correction now seems to have been wrong: Dijkstra's original results remain acceptable, being confirmed by the results of Fast and Verrijp, and the chemical work of Dr. Turkdogan and his associates.

I am surprised that Fast and Verrijp are sure about the metastable phase which is formed when α-iron saturated with nitrogen is cooled. Is the evidence for Fe_8N decisive? Could the phase not be ε 'Fe_3N' (which has a very wide composition range and can be richer in iron than Fe_4N) for the nitrogen potentials which can be calculated for the metastable phase from the equilibrium nitrogen concentrations in α-iron, would not be unreasonable for 'Fe_3N'?

Then there is the question of nitrogen in α- and δ-iron. Dr. Corney and Dr. Turkdogan assume that the values of $\Delta\bar{H}[N]$ and $\Delta\bar{S}[N]$ are the same in both phases. The evidence is not very good and it is interesting to note that with carbon it looks as though $\Delta\bar{H}[C]$ is not equal in the two phases. According to Fig. 3 of the paper, the solution of nitrogen in α-iron is made less endothermic by the presence of silicon. One would have expected silicon to make the solution more endothermic because it raises the activity coefficient of the dissolved nitrogen by a factor of 1·5. However, this is quite possible, for in view of the scatter of the results in Fig. 3, the true silicon–iron line might well have a steeper slope than the pure iron line, with perhaps equal intercepts when $1/T = 0$; i.e. equal partial entropies of solution.

The vanadium–iron–nitrogen story unfolded by Drs. Turkdogan, Ignatowicz, and Pearson is most interesting, but in some ways puzzling. Are the authors really sure that their results are accurate enough to indicate that V_2N (if there is such a nitride) is not formed at a very early stage in their alloys: 0·007% nitrogen, equivalent to V_2N in the 0·051% V alloy, would hardly be noticed in their Fig. 1. With VN the nitrogen required would have been 0·014% and this would probably have been observed. The conclusion that no vanadium nitride is formed under the conditions of their experiments is at variance not only with the admittedly poor thermodynamic data available on VN, but also with our general expectations of the nitrogen affinity of vanadium (in the series V, Cr, Mn, Fe) unless vanadium has an unexpectedly low activity coefficient in solid iron.

Dr. **R. G. Ward** (Sheffield University): I should like to discuss the earlier papers of Dr. Turkdogan and his colleagues on the liquid iron–carbon–alloy systems. The function ΔN_C^X where X is the substitutional alloying element, is of considerable interest although its fundamental significance is a little obscure.

If the function ΔN_C^X were temperature-independent, as claimed by the authors, the whole of the liquidus surface on the carbon-rich side of the ternary eutectic trough could be calculated from the knowledge of the liquidus in the binary iron–carbon system and the

position of the ternary eutectic trough which is usually well defined. The temperature independence of ΔN_C^X is thus worth investigating further.

In Fig. *A*, I have plotted all the data of Chipman and co-workers[1] for the iron–carbon–manganese system. Some of the points may be slightly inaccurate as the melts contained up to 1% silicon for which an arbitrary correction was made, but many points refer to silicon-free alloys. The points clearly fall on three isothermals, and the function ΔN_C^{Mn} is therefore dependent on temperature, and not independent as was suggested.

Dr. Turkdogan has also shown that plots fo ΔN_C^X/atom fraction of *X*, are smooth curves if *X* is P, Si, or Mn, but that an inflexion occurs when *X* is sulphur. However, if ΔN_C^S is regarded as being dependent on temperature, and curves are drawn for each temperature as shown in Fig. *B*, then the anomalous inflexion disappears. In these plots, three misleading points have been displaced, as shown by the arrows, to positions corresponding to values taken from Dr. Turkdogan's smooth curves of carbon solubility against sulphur content drawn from the same experimental data (Fig. 2 of Part II); in fact almost identical curves to those of Fig. *B* are obtained if they are calculated direct from the smooth curves of Dr. Turkdogan's Fig. 2.

As the function ΔN_C^X can no longer be regarded as independent of temperature, it loses much of its value. I would suggest that the fundamental mechanisms of the interactions between iron, carbon, and alloying elements are better discussed from consideration of the whole of the liquidus surface of the ternary equilibrium diagram, which is the unique expression of all electronic and elastic interactions, than from any attempt to use the function ΔN_C^X.

Dr. **G. M. Leak** (B.I.S.R.A.): The work by Dr. Turkdogan and his colleagues requires some comment with respect to strain-ageing properties. According to Epstein[3] it might have been expected that iron containing 0·05% vanadium and 0·01% nitrogen would exhibit no strain ageing. Since this ageing is dependent upon the amount of nitrogen in solution in the material, the present authors' results suggest that under the conditions of their experiments, vanadium will not affect strain ageing.

Using specimens supplied by Dr. Turkdogan, some ageing experiments were carried out in the Sheffield laboratories of B.I.S.R.A. Internal friction measurements were used. Quenching from temperatures within the range 200–600° C gave results both for solubility and strain ageing, which agreed with similar results for pure iron containing 0·01% nitrogen. Thus it appears that for this material, vanadium does not affect nitrogen solubility or strain ageing due to nitrogen.

Fast and Meijering[4] made internal friction measurements on iron containing vanadium and nitrogen, and showed precipitation of vanadium nitride under conditions such that vanadium would inhibit strain ageing. However, their material contained 0·5% vanadium. Perhaps Dr. Turkdogan would comment on the possible cause of this difference in result. It is possible that the high temperature (950° C) used in the experiments of Fast and Meijering might affect the formation of vanadium nitride. Accordingly in our experiments we heated some specimens in the range 950–1150° C. After slow cooling or quenching from these temperatures we found no significant changes in solubility or ageing rate.

Measurements similar to those of Fast and Verrijp on iron–nitrogen alloys have also been carried out by Thomas and myself.[5] Fast and Verrijp, together with Turkdogan, quote a heat of solution of about 8 kcal/g-atom, for the nitride found during ageing. The nitrogen solubility measured in our experiments is somewhat higher than that measured by Fast and Verrijp at temperatures of about 100° C, leading to a heat of solution of the nitride of about 6 kcal/g-atom. Our measurements also included a determination of the solubility of nitrogen in equilibrium in cold-worked iron, i.e. the solubility in equilibrium with dislocation atmospheres. This solubility is much lower than that in equilibrium with the precipitates Fe_4N or $Fe_{16}N_2$. In a similar way to the analysis of solubility measurements for equilibrium with a precipitated phase leading to a heat of solution, the measurements for equilibrium with dislocation atmospheres can be analysed leading to the binding energy of nitrogen in a dislocation atmosphere. This analysis was suggested by Dr. Richardson and gave a value for the binding energy of about 0·75 eV per nitrogen atom (about 17 kcal/g-atom).

Mr. **J. R. Brown** (G.K.N. Group Research Laboratory): In Dr. Turkdogan's paper on the solubility of nitrogen in α-iron and silicon–iron, the aluminium content of his samples was 0·003%. If aluminium nitride is formed, it would account for about 0·0015% nitrogen, which is a considerable proportion of the total nitrogen found. Has this been taken into account?

Dr. **B. B. Hundy** (Steel, Peech, and Tozer): My remarks are confined to the question of strain ageing which is raised by Dr. Turkdogan in his last paper. Towards the end of this paper he points out some so-called strain-ageing anomalies and suggests that further thought should be given to these. Some of the results he quotes, however, are not necessarily anomalous. Dr. Turkdogan says: " One should therefore expect that if a metal has a yield point, it should strain age after deformation." This does not necessarily follow, for the degree of strain ageing depends on the amount of solute available to lock the dislocations and the dislocation density after straining. It can quite easily happen that there are sufficient carbon and/or nitrogen atoms available to lock all the dislocations in the annealed steel and cause a yield point, but when the steel is worked and the number of dislocations greatly increased, there may not be sufficient solute atoms available to form atmospheres at all of these dislocations; a yield point would not then be seen on retesting. In fact this happens in the aluminium-stabilized mild steels where all the nitrogen in the steel is fixed as aluminium nitride and cannot take part in the strain ageing process. On cooling the steel after annealing, sufficient carbon atoms would segregate to

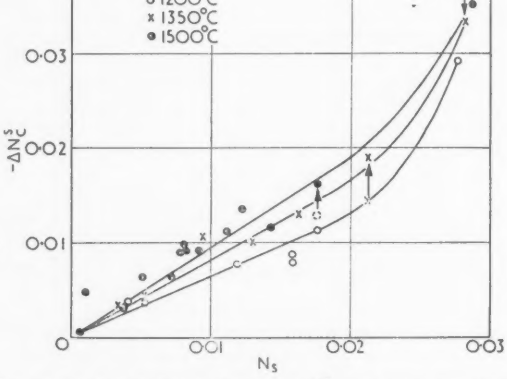


Fig. B—Relationship between $-\Delta N_C^S$ and atom fraction of sulphur, from data of Turkdogan and Hancock[2]

the dislocations to give a yield point, but when it is cold-worked, there would not be sufficient carbon atoms in solid solution (solid solubility = 10^{-7} % at room temperature) to form atmospheres around the new dislocations. There is no yield-point return on strain ageing these steels until they are heated to about 200° C, where the solid solubility of carbon is greater.

There is no doubt that strain ageing can sometimes occur in aluminium-stabilized steels, but I think that we need a great deal more data on the thermodynamics of the reaction between aluminium and nitrogen in mild steel before we can say that this behaviour is anomalous. My own experiments have indicated that an aluminium-killed steel can be transformed from a non-ageing steel to an ageing one simply by heating to about 800–900° C; this behaviour was found even though the specimens were very slowly cooled. Present thermodynamic data suggest that this behaviour should not occur until much higher temperatures, and it should not really be observed after slow cooling. This behaviour is only anomalous when compared with the theory, and probably means that the theory needs modifying.

Turning to Dr. Turkdogan's own results; might it not be possible that at 500–600° C the rate of combination of nitrogen and vanadium is too slow to make any detectable difference to the solubility of the nitrogen, and it is only at higher temperatures that such an effect can be observed? At very high temperatures the vanadium nitride will dissociate, so that in this case, too, the solubility of nitrogen should not be affected. I think that it may be worthwhile extending this work to cover a wider temperature range in order to settle this point. Finally, is Dr. Turkdogan absolutely sure that the vanadium in his specimens was in the free metallic state?

CORRESPONDENCE

Mr. **R. Rawlings** (University College, Cardiff) wrote: In the paper by Turkdogan, Ignatowicz, and Pearson, it is unfortunate that the investigations were confined to very low vanadium contents. The writer carried out a trial on the steels used by Jones and Coombes[6] in their investigation on strain ageing. The analysis of the steels used is given by these authors; the high-purity iron used was supplied by B.I.S.R.A. Several steels were nitrided at 800° C in an NH_3–H_2 atmosphere, and subsequently analysed for nitrogen. The results in Fig. *C* show apparent signs of precipitation of VN. If one makes use of the free energy of formation of vanadium nitride given by Pearson and Ende,[7] it can be calculated that a_V (referred to pure vanadium) = $1{\cdot}38 \times 10^{-5}$ for 0·085% V and $\gamma_V = 0{\cdot}15$, somewhat higher than the 0·12 given by Chipman[8] for infinitely dilute solutions at 1600° C, and much higher than is implied by the results

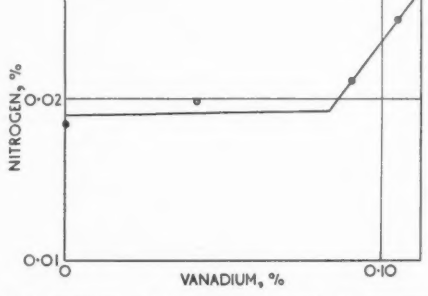


Fig. C—Variation of N content with V content for constant N potential

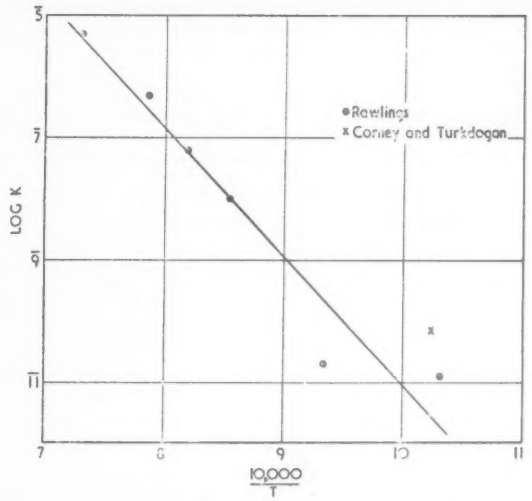


Fig. D—Temperature variation of the solubility of silicon nitride in ferrite: $K = [Si]^3[N]^4$

of the present authors. Use has been made of the solubility of nitrogen at one atmosphere in ferrite found by Fast and Verrijp,[9] and of Sievert's law. There appears to be no real contradiction between the results of the present paper and those of Jones and Coombes, as even with a vanadium content as low as 0·05% in solution, most of the nitrogen can be expected to be precipitated by the time the steel has cooled to room temperature. It is true that the writer's results apply to a commercial steel and not to the ternary Fe–V–N alloy, but they do at least establish the order of magnitude of γ_V.

The paper by Corney and Turkdogan is to be welcomed as it adds to our knowledge of the solubility of nitrogen in ternary systems. As seen in Fig. 3 of their paper, the concentration of nitrogen in ferrite in the presence of silicon nitride is very small, and is difficult to determine accurately. The writer has been engaged on similar work, and it may be appropriate to quote some of his results relative to the present paper. Partly to avoid the particular difficulty of the determination of low nitrogen contents, he has used lower silicon contents so that silicon nitride precipitates at higher nitrogen concentrations. The latter were obtained in the usual way by nitriding in atmospheres with controlled ammonia contents. The solubility of silicon nitride in ferrite may be expressed as:

$$K = [Si]^3 [N]^4$$

Admittedly, activities should be used, but at this stage the use of concentrations is thought to be sufficiently accurate. The writer's results are shown in Fig. *D*, together with that of Corney and Turkdogan (derived from their Fig. 3). The agreement is seen to be satisfactory. From the slope of the curve, it may be calculated that the heat of solution of silicon nitride in ferrite is 97,000 cal/mol. This is in agreement with that calculated from the heat of formation of silicon nitride, and with the heats of solution of silicon and of nitrogen. It has been assumed that the silicon nitride contains a negligible amount of iron. The temperature variation of the solubility of silicon nitride in γ-iron has been found to be approximately the same but the values of $K\gamma$ are from 10^2 to 10^4 times the values of K_α.

Combining values for the solubility of silicon nitride in α-iron with the values for the equilibrium between

solid silicon, nitrogen gas, and silicon nitride,[7] the activity and hence the activity coefficient of silicon in solid solution may be determined. Thus at 1000° C $a_{Si} = 8 \times 10^{-5}$ for [Si] = 1·9% and $\gamma_{Si} = 8{\cdot}6 \times 10^{-3}$, if the activity of pure silicon is taken as unity. These figures are approximate only, but are believed to be of the correct order. They are in qualitative agreement with those for liquid solutions deduced by Chipman.[10]

AUTHORS' REPLY

Dr. **Turkdogan** and his co-authors wrote: The authors would like to thank all those who have taken part in the discussion of a series of papers on the solubilities of graphite and nitrogen in iron and iron alloys.

In reply to Dr. Richardson's question on the method of calculating γ_C in iron–silicon–carbon melts, reference should be made to a recent paper by Turkdogan,[11] who has shown that the effect of an alloying element on the activity coefficient of a solute in iron may be expressed as

$$Q_Y^X = \frac{\gamma_Y^X}{\gamma_Y^Y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where γ_Y and γ_Y^Y are the activity coefficients of the solute Y in the ternary and binary systems at the *same activity of Y*. As evidenced by all the available data on solid iron–silicon–carbon and liquid iron–carbon–silicon, iron–chromium–carbon, and iron–alloys–sulphur, the term Q_Y^X is independent of the activity of solute Y but is a continuous function of the concentration of the third element X at a given temperature. In view of this evidence there remains little doubt about the validity of the assumption made previously in calculating γ_C in iron–silicon–carbon melts.

Since the discussion of these papers, further work has been done on the solubility of carbon in iron–manganese and pure manganese melts.[12, 13] The results given in these papers indicate that Fig. *A* drawn by Dr. Ward from the results of Chipman *et al.*[1] is not right, particularly with respect to the presence of minima. The authors agree with Dr. Ward that the variation of ΔN_C^S with N_S, shown in Fig. *B*, may depend on the temperature of the melt.

With reference to the paper on nitrogen in iron and iron–silicon alloys, Dr. Richardson pointed out that $\Delta\bar{H}$ and $\Delta\bar{S}$ may not be the same in α and δ phases. The authors, however, feel that the present results, plotted in Fig. 2 on p. 345 of the paper by Corney and Turkdogan, do not show any change in the value of $\Delta\bar{H}$ and $\Delta\bar{S}$ in α and δ phases. The authors agree with the remark made by Dr. Richardson on the slope of the curve in Fig. 3 on p. 346. It is most unlikely that the partial molal heat of solution of nitrogen in 2·8% Si-iron alloy will differ, to a measurable extent, from that in pure α-iron. The solubility of nitrogen in 2·8% Si–iron alloy in equilibrium with 1 atm pressure of nitrogen may, therefore, be reformulated as follows:

$$\log [\%N] = -\frac{1980}{T} - 1{\cdot}022 \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Since in this alloy a silicon nitride forms at 705° C, it follows from equation (2) that nitrogen in solid solution in equilibrium with a silicon nitride is about 0·0009%.

The authors are grateful to Dr. Leak for measuring the ageing characteristics of 0·05% vanadium–iron alloy by the internal friction method. As pointed out by Dr. Leak, this alloy did not show any non-strain ageing property. Reference should now be made to the work of Fast and Meijering,[4] who showed that VN was formed in iron containing 0·46% vanadium after a nitriding treatment at 950° C; this, however, does not contradict the results of the present work on iron containing 0·05% vanadium. As indicated in Fig. *E* (drawn schematically) for a given nitrogen in solid solution, the temperature at which a vanadium nitride forms increases with increasing percentage of vanadium in iron. Alternatively, for a given temperature, nitrogen in solid solution in equilibrium with a vanadium nitride phase increases as the vanadium content of the iron decreases.

Mr. Brown raised the question of the aluminium nitride formation in 2·8% Si–iron alloy which contained 0·003% aluminium. Very little nitrogen is expected to be tied up by this aluminium for the following reasons:

(i) Some of this aluminium may be in the form of alumina

(ii) Remainder of the aluminium in solution will not all combine with nitrogen because of the state of equilibrium in the reaction

$$[Al] + [N] = AlN$$

(iii) In the presence of a relatively large proportion of silicon (i.e. 2·8% Si) aluminium nitride may decompose in the manner

$$4AlN + 3[Si] = Si_3N_4 + 4[Al].$$

Traces of aluminium will not, however, affect the temperature at which silicon nitride was found to form.

The authors agree with the remarks made by Dr. Hundy on the phenomenon of the return of the yield point after heat-treatment at about 200° C. With regard to aluminium-stabilized steels, it is fair to say that the work of Darken, Smith, and Filer[14] provides adequate thermodynamic data to predict the conditions of nitride formation in iron containing aluminium. Although these investigators determined the solubility product of aluminium nitride within the austenite field, their results can be extrapolated without an excessive error to a temperature within the ferrite range. Calculations show that iron containing 0·05% aluminium in solution will be in equilibrium with aluminium nitride at 700° C in the presence of about 2×10^{-6}% nitrogen in solution, which could be regarded low enough to prevent strain ageing. In practice, however, it is observed that aluminium-stabilized steel is subject to strain ageing when the annealing temperature after cold work exceeds 650–700° C. Obviously these two facts are conflicting, and indicate that further thought should be given to the causes of strain ageing.

For example, attempts should be made to prove whether *aluminium nitride* could diffuse into dislocations. If this does happen, one would then expect a change in the non-strain-ageing property of the stabilized steel as a result of an increase in the rate of diffusion of the nitride with annealing temperature.

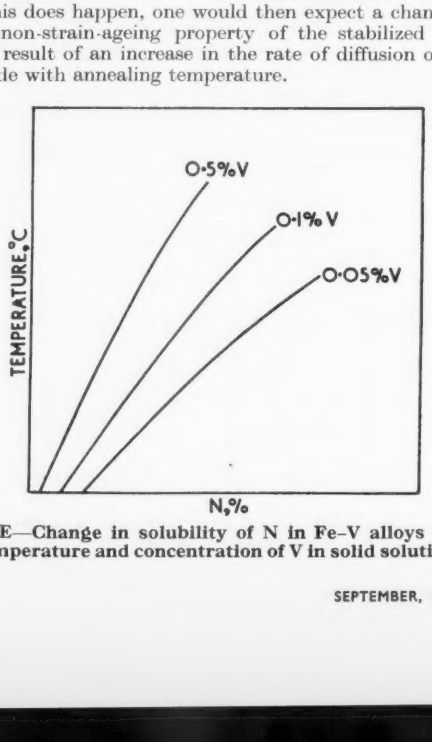


Fig. E—Change in solubility of N in Fe–V alloys with temperature and concentration of V in solid solution

The authors would like to thank Mr. Rawlings for his contribution containing some of his experimental results. Figure *C* drawn by Mr. Rawlings indicates that a vanadium nitride is formed at 800° C in the presence of about 0·1% vanadium and 0·02% nitrogen in solution. As pointed out by the authors in their paper, further work will be carried out on the thermodynamics of nitrogen in iron containing larger proportions of vanadium; until the results of this investigation become available, there is little to be said on this matter.

Since the publication of the papers on nitrogen in iron alloys under discussion, more work has been carried out on nitrogen in iron–silicon alloys, and the results of Mr. Rawlings given in Fig. *D* will be considered in detail at a later date. It should, however, be pointed out that, in view of a slight change in the slope of the log [%N] *v.* $1/T$ curve for 2·83% Si–iron alloy (*see* equation (2)), the value of log $[\%Si]^3[\%N]^4$ at 705° C and 2·83% Si becomes $\overline{11}\cdot46$, which agrees well with the line in Fig. *D*.

REFERENCES

1. J. CHIPMAN *et al.*: *Trans. Amer. Soc. Metals*, 1952, vol. 44, pp. 1215–1230.
2. E. T. TURKDOGAN and R. A. HANCOCK: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 155–159.
3. S. EPSTEIN: U.S. Patent 2356, 450. 22nd August, 1944.
4. J. D. FAST and J. L. MEIJERING: *Philips Res. Rep.*, 1953, vol. 8, No. 1, pp. 1–20.
5. W. R. THOMAS and G. M. LEAK: *Proc. Phys. Soc.*, 1955, vol. 68*B*, pp. 1001–1007.
6. W. R. D. JONES and G. COOMBES: *J. Iron Steel Inst.*, 1953, vol. 174, pp. 9–15.
7. J. PEARSON and U. J. C. ENDE: *Ibid.*, 1953, vol. 175, pp. 52–58.
8. J. CHIPMAN: "Basic Open Hearth Steelmaking," p. 638: 1951, New York, A.I.M.M.E.
9. J. D. FAST and M. B. VERRIJP: *J. Iron Steel Inst.*, 1955, vol. 180, pp. 337–343.
10. J. CHIPMAN *et al.*: *Acta Met.*, 1954, vol. 2, No. 3, pp. 439–450.
11. E. T. TURKDOGAN: *J. Iron Steel Inst.*, 1956, vol. 182, pp. 66–72.
12. E. T. TURKDOGAN, R. A. HANCOCK, S. I. HERLITZ, and J. DENTAN: *Ibid.*, 1956, vol. 182, pp. 274–277.
13. E. T. TURKDOGAN, R. A. HANCOCK, and S. I. HERLITZ: *Ibid.* (in press).
14. L. S. DARKEN, R. P. SMITH, and E. W. FILER: *Trans. Amer. Inst. Min. Met. Eng.*, 1951, vol. 191, pp. 1174–1179; *J. Met.*, 1951, vol. 3, Dec.

DISCUSSION ON DELTA-FERRITE

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parenthesis):

"Metallography of Delta Ferrite," *by Kehsin Kuo:*
Part I (1954, vol. 176, April, pp. 433-440).
Parts II, III (1955, vol. 181, October, pp. 128–137).
Parts IV, V (1955, vol. 181, November, pp. 213–227).

The papers were presented by Mr. Kuo (Royal Institute of Technology, Stockholm).

Mr. **T. H. Arnold** (Hadfields, Ltd.): I would like to pay tribute to the excellence of Mr. Kuo's photomicrographs and the obviously thorough manner in which the the microstructures have been analysed and studied in order to extract every scrap of evidence likely to assist in their interpretation.

I have nothing but admiration for the manner in which a mass of data has been presented and so lucidly and logically discussed. Amongst the various methods used to examine the constituents there is no mention of the magnetic etching method which was described originally by Avery *et al.* in *Metals and Alloys* in 1939. This method has been in use in Hadfields laboratories since then, and has proved extremely useful in determining the difference between magnetic phases and non-magnetic phases in microstructures.

The observation at the end of Part IV, that the δ-eutectoid would presumably not appear in low-carbon 18/10/3 Cr–Ni–Mo steels, suggests the importance of carbon. Possibly, small changes in the carbon content may have much more effect on transformation mechanisms than large changes in alloy content; what is Mr. Kuo's opinion on that? Has he ever found in the X-ray crystallographic examination of extracted residues, any evidence of a phase with an austenitic type of structure of the type of carbide observed and described recently by Dr. Goldschmidt? I think that it was designated ψ; would Dr. Goldschmidt confirm this ?

In discussing the formation of the σ-phase, Mr. Kuo dealt at length with the mechanism of its formation from ferrite. Would he care to give his views on its formation directly from austenite, because there are quite a number of alloys in which we have found σ but not ferrite, prior to heating in the range at which σ is formed.

Interest in δ-ferrite arises from technical problems connected with the manufacture and use of alloys which possess special high-temperature properties, from the aspect of creep-resistance and/or resistance to scaling combined with high strength. These alloys have carbon contents in excess of 0·1%, and maybe as high as 0·5%, and possess microstructures in which austenite, carbides, and ferrite of δ origin may be present. Metallographers actually concerned with the examination and testing of heat-resisting alloys of the chromium–nickel–tungsten type will be familiar with many of the structures illustrated by Mr. Kuo's photomicrographs. Hence a fuller understanding of the mechanism responsible for their production is essential in the investigation of manufacturing irregularities and service failures.

During my early experience with the hot rolling of a particular chromium–nickel–tungsten heat-resisting steel, bars which had cracked on the corners during rolling were occasionally encountered. On micro-examination, the uncracked bars were found to have a completely austenitic structure, whereas in addition to the austenitic grains, the defective bars had grains of a lamellar structure similar in appearance to the δ structure shown by Mr. Kuo. At that time, the presence of the lamellar-structure grains was considered to be responsible for the cracking, and their origin was ascribed to overheating. A reduction in the reheating temperature when rolling served to reduce substantially the number of cracked bars. The differences in structure between the good and bad bars, however, may not have been due to temperature differences but could possibly be explained by a mechanism such as is illustrated in Fig. 1 of Part II for the case of the 18/4 W–Cr high-speed steels. By postulating compositional differences between casts or variable amounts of decarbonization, the good bars could have been in the austenite + carbide field of the diagram at the high temperature for rolling, whereas the defective bars at the same temperature could have been in the austenite + ferrite + carbide field.

More recently, differences in both room-temperature and high-temperature properties of a number of chromium steels containing additional carbide-forming elements appeared to be attributable to small compositional differences influencing the presence or absence of δ-ferrite. The composition limits in the manufacture of alloys of this type are frequently so narrow that it is not always possible to avoid the unwanted presence of δ-ferrite. If a method could be found of eliminating δ-ferrite from a commercial steel in which it has been accidentally obtained, it would undoubtedly be of outstanding interest to the practical steelmaker, provided it did not at the same time introduce other deleterious products, e.g. σ.

A more precise knowledge of the phase boundaries and transformation mechanisms of these alloy systems constitutes a most important aspect of steel research, and thanks are due to Mr. Kuo for his important contributions to the metallography of δ-ferrite.

Dr. **H. J. Goldschmidt** (B.S.A. Group Research Centre, Sheffield): In Part II, is it correct to express the main conclusion by saying that segregation is to a large extent due to the competitive nature of the eutectic and the peritectic reaction immediately after cooling from the liquid, so that differences in the precise manner and rate of cooling over this narrow high-temperature interval would cause variations in the degree of approach to equilibrium? In that case, can some lack of equilibrium ever be avoided? It seems possible that a uniform and reproducible structure might be obtained by extremely slow cooling from the liquidus or by very long-time holding at about 1330° C in a vacuum or neutral atmosphere, or would Mr. Kuo say that there is little chance of this? Also, it seems that any such variations in the degree of completion of the δ-ferrite reaction should be reflected in small differences in phase constitution at lower temperatures, and possibly in lattice spacings of the matrix and carbide phases, because these will inherit part of such composition differences from the time of their nucleation.

The second point concerns the carbide M_6C which occurs in high-speed steels and has generally been referred to by the author as Fe_3W_3C, as though the composition were invariable, apart from a small amount of chromium. Is it implied that it is always this carbide composition which co-exists with the matrix, and not Fe_4W_2C of an intermediate iron/tungsten ratio, as previously assumed? Also, the carbon content in the carbide is not necessarily rigidly constant and fixed to M_6C, but may vary with the iron/chromium/tungsten ratio. There is certain evidence for this varying interstitial carbon content in η and other alloy carbides, which would imply a defect lattice, just as is the case in the simpler carbides such as TiC or V_4C_3. This shows remarkably during decarburization and Fig. *A* reveals this. This is a photomicrograph, × 1000, of a solid piece of η-carbide as extracted in powdered form from the steel, then pressed and sintered. During this process it suffered a certain amount of decarburization, as was shown by the presence of some Fe_7W_6 found on X-ray examination. X-rays also showed a heterogeneous range of η-carbide composition through carbon loss within the lattice. The slide shows a curious optical interference effect inside several of the large single carbide crystals, rather like Newton's rings. Inside any one carbide grain, loss of carbon occurred from the centre to the outside to merge into the surrounding intermetallic compound. The interference fringes may arise through a small variation in the degree of attack on etching to give a slight curvature with varying carbon content.

Figure *B* shows the same effect in another example. This is an extreme case and not likely to occur normally in high-speed steel, but in principle it can occur and is of interest in connection with the present paper, as it raises the point of whether such composition changes should not be considered as an important further variable. Something similar may well occur in the $Cr_{23}C_6$ carbide, in first losing lattice carbon and then transforming into σ. This is not yet certain, but such a process of carbide → σ transition may well have occurred in some of the author's later samples in Parts III and IV, though the main σ formed directly from ferrite.

In Part IV, on p. 221, Mr. Kuo says that it is still not known why chromium is the least effective element, compared with vanadium, molybdenum, and tungsten, in modifying the iron–carbon diagram. Does it not mean that it is relatively the weakest carbide-former, and is this not to be expected on many grounds, including electron theory and the position of chromium in the periodic table, next to manganese?

Dr. **B. Cina** (Brown-Firth Research Laboratories): In Part I, when dealing with a 0·2/8·15 C–Mo, less undissolved carbide, M_6C, was observed in the δ than in the former γ region on heating the alloy to 1150° C, from which the author concludes that more carbide was dissolved in the δ than in the γ. This is difficult to accept. Could not it be that, as γ forms at 1150° C, carbon diffuses from the δ into the new austenite, in which it will be more soluble? This establishes a composition gradient of carbon in the δ which allows all the undissolved carbide gradually to be dissolved in the δ and transferred by diffusion to the austenite. This would also be facilitated by the faster rate of diffusion of carbon in δ than in austenite.

On the identification of the lamellar constituent, Mr. Kuo states that an electrolytic extract from a sample furnace cooled from 1300° to 1050° C, and which showed a lamellar transformation product, was found to contain only Fe_3Mo_3C. This is taken as proof that the lamellar constituent is this carbide. Is Mr. Kuo satisfied that his extraction technique would have given him any plain iron–molybdenum compound had any been present in addition to the double carbide? Further, did he try X-ray diffraction technique for the identification of his lamellar phase in the solid sample? This is a most important point which should be unequivocally established at the outset. Further confirmation of the identification of the lamellar constituent would therefore be welcome.

On Part II, and dealing with the possibility of nitrogen pick-up, since tungsten as well as chromium and vanadium has a strong affinity for nitrogen, the wisdom may be questioned of treating samples which are only 3 × 3 × 3 mm in a nitrogen atmosphere at temperatures as high as 1350° C. It would be interesting to know the nitrogen content of samples given by Mr. Kuo both before and after such treatment. Are the same metallographic features observed after treatment in an inert atmosphere (e.g. argon) as after treatment in N_2?

This question is pertinent to all five parts of the paper under discussion. The 8% molybdenum, the 18% tungsten, and the 27% and 18% chromium alloys would all readily form nitrides of these elements, and the absorption of such nitrogen at these high temperatures would alter the alloy balance and therefore the ratio of γ to δ formed at these elevated temperatures. In addition, the nitrogen might also become involved in the σ eutectoid structure. What are Mr. Kuo's comments on this important issue?

In Part III, dealing with the 27% chromium, 5% nickel, 1½% molybdenum alloy, the interpretation of

Fig. A—Photomicrograph of steel-extracted and sintered M_6C carbide compact, showing partial decarburization and varying carbon content within carbide grains × 1000

[*Discussion Delta-ferrite*
[*To face p.* 58

Fig. B—Photomicrograph of steel-extracted and sintered M_6C carbide compact, showing partial decarburization and varying carbon content within carbide grains × 1000

Discussion Delta-ferrite]
To face p. 59]

Figs. 4*a* and *b* may be questioned, i.e. the nature of the precipitate in the 1250° C water-quenched sample. Mr. Kuo claims that the fine precipitated particles are austenite. If this were so, they would have formed when the alloy intersected the knee of the ferrite-to-austenite transformation curve at about 950° C in Fig. 1. Therefore it follows that all samples quenched to a temperature below this knee should show the same precipitate structure, but in fact they do not seem to do so; thus this precipitate is absent from Figs. 8, 9, and 10, in the samples quenched to 800° C and held for only 10 min. The less severe quench (to 800° C), as compared with quenching to room temp., should have given even more of these austenite particles, if such they were.

It is suggested, therefore, that these particles are carbides precipitated on quenching and at a temperature less than 800° C. The fact that they are absent from Fig. 3, on quenching from 1150° C, is probably due to the greater amount of the carbon being concentrated in the austenite pools, stable at that temperature. A precipitate similar to that in Fig. 4 is observed in plain 20% and 30% chromium irons on water-quenching from about 1100° C, at which temperature these alloys are fully δ-ferrite. This precipitate can be spheroidized at *c.* 800° C, when it is identifiable as chromium carbide.

Finally, Figs. 6 and 7 seem to be confused, since only pro-eutectoid austenite is shown after 1 h at 1000° C in Fig. 6, while Fig. 1 shows that δ-eutectoid should also be present after this time.

In Part IV (the decomposition of δ-ferrite between 650° and 1000° C in a low-carbon 18/10/3 Cr–Ni–Mo steel) Mr. Kuo's choice of steel for this work was perhaps unfortunate, in that this alloy had to be treated at a temperature as high as 1350° C to obtain only 20% of δ-ferrite. It is known that the difference in composition between δ and γ decreases as the temperature increases. Subsequent treatment of this alloy at a temperature lower than 1350° C would be expected to result in a more rapid transformation of δ to austenite than would be the case had an alloy been chosen which could have formed δ more readily at a temperature lower than 1350° C, such as 1050° C, which is commonly used for the 18/8/Mo-type alloys. In the latter case there would have been a greater initial difference in composition between the δ and γ phases formed at 1050° C than in the author's alloy at 1350° C. Thus, it might be expected that the mechanism of the transformation of δ to γ or of δ to γ + σ would not necessarily be the same for both such alloys. Relatively little diffusion of chromium would be required to cause the δ formed at 1350° C to transform to austenite at lower temperatures, because the δ and γ are initially so similar in composition that the δ should transform very easily.

Furthermore, the time required for σ formation in such an alloy would be proportionately increased. The reverse would be true for a δ which had been formed at 1050° C then treated at some temperature lower than 1050° C, because then the transformation of δ to γ would be slower and that of δ to σ would be more rapid, relative to the transformation of δ in the case of the 1350° C alloy. The actual appearance of the γ or γ′ laths or cones, as they are sometimes called, observed in Mr. Kuo's micrographs, suggests that the δ → γ′ transformation is coherent, and the very rapid formation of the γ′ also suggests that a transformation mechanism more of a bainitic or martensitic character takes place at these temperatures, rather than one more dependent on alloy diffusion.

A further point is that this alloy was again treated for 5 min at 1350° C in an atmosphere of nitrogen, and the same objections could be raised as mentioned before.

There is also the question of carbide precipitation in connection with the δ-eutectoid. It is difficult to understand why the δ itself in any of the alloys studied by Mr. Kuo should be able to provide all the carbon necessary to form austenite-carbide aggregates. It is known that the solubility of carbon is much greater in γ than in δ, and therefore in an alloy such as the 18/10/3 Cr-Ni-Mo, containing only 0·046% carbon, all or the greater part of the carbon should be in solution in the austenite, especially at 1350° C. The carbon content of the δ would then be very low indeed, perhaps less than 0·01%. Even if there is this carbon in solution in the δ, when the δ transforms to austenite it would be more reasonable for this carbon to be retained in solution in the new austenite rather than precipitated with it as a γ-carbide aggregate.

A careful examination of the author's photomicrographs, such as Fig. 5*b*, reveals that carbide is precipitated most commonly at or near the former δ-γ boundaries. Surely a more plausible explanation is one which I have already given* i.e. carbon is diffused from the original carbon-rich but chromium-poor austenite into the new carbon-poor and chromium-rich γ′ formed by transformation from the δ. Since the solubility of carbon in austenite decreases with increasing chromium content, precipitation of $M_{23}C_6$ would then occur in this chromium-rich γ′. I suggest that where γ′ also forms by acicular growth into the δ, as in Fig. 5*a*, it carries this carbon with it, from the austenite outside; hence its occasional precipitation well within the former δ pools. The precipitation of carbide would then simply be a side reaction and not one primarily governing the decomposition of the δ.

Again, one might generalize here. Occasionally in the 'discussion' sections of certain of his papers, Mr. Kuo refers to the possibility of carbon for the δ eutectoid being provided from the adjacent and original γ pools. Interpreting the decomposition of the δ-ferrite, insufficient attention seems to have been given to this source of carbon. Its origin in the parent γ means that the formation of δ-eutectoid is not strictly analogous to that of pearlite, since in the latter case it is the parent γ which transforms to ferrite and carbide. In the case of the δ-eutectoid, the original δ transforms to γ′, while the original γ provides the carbon for the eutectoid carbide.

Finally, the author showed us a photograph of the surface of a sample heated in vacuum. There were undulations on the surface, and he suggested that these represent a volume change associated with the transformation. It is possible to get unusual effects by heating a polished sample in vacuum; has Mr. Kuo tried a similar heat treatment on a stable phase in vacuum, e.g., taking stable austenite and heating it up to 700–800° C and noting whether there were any effects on the surface. Work on this subject published some time ago showed that if copper was heated in vacuum and no phase transformation was involved here, similar effects could be obtained on the surface.

Mr. **Arnold:** I suggest that Fig. *B* may not show the correct structure of the material underneath. Photomicrographs of that kind often illustrate the structure of the film on the surface of the metal which has nothing to do with the structure of the metal underneath. Can Dr. Goldschmidt tell us whether that has been investigated. It will be useful to know that before these photographs are regarded as evidence.

Dr. **Goldschmidt:** I fully agree with Mr. Arnold that a thin surface film must have been present and indeed must

* B. Cina, *J. Iron Steel Inst.*, 1952, vol. 171, pp. 229–237.

have been an essential feature in accounting for the effect observed. But the film (of whatever nature) was merely an incidental artefact, which, though normally undesirable, was in this instance turned to good account, in helping to reveal the existence of surface curvature, which, without it, would not have shown. I suggest that the contours seen are definitely related to the outline of the underlying grains; an examination shows many places where the topography as indicated by the fringes is clearly associated with grains within which they occur, and with their outer shape and size.

The only reason for mentioning this is to demonstrate the existence of variations in etching depth within the carbide grain and thus in composition, illustrating a point in my original comment on the paper; I apologize if explaining this lesser issue has diverged rather far from Mr. Kuo's subject.

CORRESPONDENCE

Professor Emeritus **A. Hultgren** (Sweden) wrote: In Fig. 1 (Part II) of Mr. Kuo's paper, the boundary between the fields A + F + C, and A + C is of particular interest. In the simplified ternary diagram, the area A + F + C is built up from tie line triangles A − F − C. If those are followed from 785° C towards higher temperatures it is seen, to begin with, that the three-phase equilibrium is eutectoid in character (reaction on heating: F + C → A). At a certain higher temperature, however, this turns into a peritectoid equilibrium (reaction on heating: C → A + F),* as indicated by the shape of the broken line towards (i). The first appearance of δ-ferrite on heating steel M, before fusion, is due to this peritectoid reaction.

As Mr. Kuo has ably demonstrated, such δ-ferrite, on cooling at a suitable rate, may be converted into a mixture of austenite and carbide, in the manner of a eutectoid decomposition. The expected reversal of the peritectoid reaction is not observed in the structure.

This appararent discrepancy is, very likely, connected with local deviations from equilibrium caused by the difference in rates of diffusion of carbon and other alloying elements, and, perhaps, by different rates of nucleation of carbide in ferrite and in austenite. It is conceivable that, on sufficiently slow cooling, the eutectoid feature would not appear.

Mr. **A. E. Nehrenberg** (Crucible Steel Company of America) wrote: Throughout his papers, Mr. Kuo has frequently referred to work published by the present writer on the same subject, and it is gratifying to learn that the observations made in these independent investigations carried on more or less simultaneously are in such good agreement.

Like Mr. Kuo, I was impressed with the fact that the δ-ferrite decomposition reaction exhibits the characteristics of the pearlite reaction. This was not referred to as a eutectoid reaction, however, for the following reason. In the case of the pearlite reaction, the overall composition of a pearlite colony is the same as that of the austenite from which it formed. It was considered a fundamental condition of a eutectoid reaction. In the case of the δ-ferrite decomposition reaction, long-range diffusion of carbon from the austenite (γ) occurs, with the result that the area of transformed δ-ferrite contains much more carbon than was present in the δ-ferrite before the transformation began. The more cumbersome expression 'aggregate of lamellar carbides in austenite' was used to describe the decomposition product of δ-ferrite because it was not felt that it could be properly termed a eutectoid. It is certainly convenient to use the term 'δ-eutectoid' to describe this microstructure, but is this proper usage, since the area undergoing transformation also undergoes a change in carbon content?

In Part I, Mr. Kuo shows that the alloy carbide disappears first in the ferrite during heating for austenitizing. This has also been observed by the present writer, not only in high-alloy steels, but in low-alloy and carbon steels as well.[1, 2] In the case of the high alloy steels, the explanation offered by Mr. Kuo for this phenomenon is in this writer's opinion essentially correct. However, it seems that the higher rate of diffusion of carbon in ferrite than in austenite accounts for the more rapid solution of carbides in ferrite than in the austenite of carbon and low alloy steels.

The formation of the aggregate of lamellar carbide in austenite is undoubtedly nucleated by an alloy carbide. Both Mr. Kuo and I have reached this conclusion independently. Mr. Kuo cites Fig. 7*b* of his paper as metallographic evidence that this is the case. In my work many specimens were carefully examined for evidence such as this but none was found. The micrographs shown in Figs. 16*a* and *b* of a paper[3] describing the writer's experiments illustrate early stages in the transformation of δ-ferrite to the pearlite-like aggregate and are typical of the observations made and do not show carbide as the leading phase. It appeared that the edgewise growth of lamellar carbide just kept pace with the advancing austenite boundary and did not precede it.

Figure 7*b* of Mr. Kuo's paper represents a specimen which was cooled continuously from 1300° to 1050° C in 10 min. It is quite possible that during the final stages of this cooling, the austenite boundary stopped advancing and began to recede. At a somewhat lower temperature than that at which the lamellar aggregate structure forms from δ-ferrite during continuous cooling the austenite matrix (γ') may begin to transform to ferrite. This transformation simply involves the movement of the ferrite/austenite boundary in such a direction as to consume the austenite. When this transformation is proceeding, the ferrite boundary assumes the convex curvature. At the completion of this transformation there is no evidence of the former boundary between the δ-eutectoid and the untransformed ferrite. Figure 13*b* of Mr. Kuo's paper is an example of this. The ferrite boundary in Fig. 7*b* has assumed the convex curvature and this might be interpreted as evidence that the untransformed ferrite is starting to consume the austenite of the aggregate.

To avoid this possible ambiguity in interpretation, it is preferable that the observations be made on samples isothermally transformed for various times so that various stages in the growth of the aggregate structure can be observed. When this was done, in the work of the present writer, no definite evidence could be found that either one of the participating phases preceded the other. In Mr. Kuo's paper, Fig. 12*a* (Part I) and Figs. 7*a*, 9*a*, and 13*a* (Part III) are typical of this writer's observations in that they fail to show any conclusive evidence that the carbide is the leading phase.

In connection with the discussion of veining in Part III, the quenching conditions employed in the work of the present writer were such that veining was not produced in the ferrite unless austenite was formed during the quench. The specimens used were $\frac{1}{2} \times \frac{1}{2} \times \frac{3}{16}$ in. and they were quenched into water at room temperature. Both a drastic quench and the volume change accompanying the allotropic transformation of ferrite to austenite were required to produce veining in the samples examined. This does not preclude the possibility that veining can be produced without the phase change provided the quench is drastic enough.

* cf. the change from eutectic to peritectic equilibrium in the system Fe–Ni–Cr.

In agreement with Mr. Kuo, the writer found that veining was not produced when the austenite was formed more slowly during an air cool.

In conclusion I congratulate Mr. Kuo for presenting his comprehensive data and observations on this new transformation with such clarity.

AUTHOR'S REPLY

Mr. **Kehsin Kuo:** I should like to thank the contributors to the discussion for the interest shown in my papers and for their kind remarks.

Mr. Arnold has rightly mentioned the usefulness of the magnetic etching method for the differentiation of a ferromagnetic phase such as δ-ferrite from a paramagnetic phase such as austenite. However, the usefulness of this method is very much reduced when one is dealing with a phase of very small particle size, as sometimes is the case in the present investigation.

In the presence of δ-ferrite, the formation of the σ phase very seldom occurs in the chromium-poor austenite. It has been shown by Morley and Kirkby[4] that in a 25/20 Cr–Ni austenitic steel σ can form directly from austenite, though this requires a very long time and the σ phase very often shows a plate-like habit.

In my X-ray examination of the minor phases in Cr–Ni corrosion-resisting steels I have not encountered the carbide phase with a NaCl type of structure which has been reported earlier by Dr. Goldschmidt.

It is very interesting to learn Mr. Arnold's experiences with the hot-rolling property of a Cr–Ni–W heat-resisting steel. I think both overheating and decarburization will promote the formation of δ-ferrite at the rolling temperature, thus causing the observed hot-shortness.

As has been pointed out in Part V, carbon is much more effective than *M* in modifying the phase diagram of the various Fe–*M*–C systems. Consequently, a small change in the carbon content may have a much larger effect on the constitution and possibly also on the transformation mechanism of high-alloy steels than a large change in the alloy content. Both carbon and nitrogen are very effective in suppressing the formation of δ and to a less extent also the formation of σ; but the presence of large amounts of these elements may at the same time have other deleterious effects.

In reply to Dr. Goldschmidt, I would like to add that it is not impossible to allow the 18/4/1 high-speed steel to solidify and cool under equilibrium conditions by extremely slow cooling, but this is very difficult to realize in practice. Carbide segregation still remains one of the main troubles of the high-speed steel producers.

I used the formula M_6C for the η carbide mainly for the sake of convenience. As is known, the metal composition of this carbide varies within broad limits, and the formula Fe_4W_2C is considered to be the nearest approach to the analysed composition. However, from the structure analysis of Westgren,[5] the formula Fe_3W_3C represents the ideal composition of this double carbide.

It is of great interest to note the observation made by Dr. Goldschmidt on the decarburized η carbide, and the exchange of opinions between him and Mr. Arnold. The monocarbides, like TiC and VC, are known to have very wide solubility ranges, e.g. $TiC_{1\cdot0}$ to $TiC_{0\cdot28}$, but it seems that the metal to carbon ratio of the η carbide is fairly constant. Naturally, this does not exclude the possibility of a very small difference in carbon content in this carbide, and the difference is enough to establish a concentration gradient for the diffusion of carbon.

I fully agree with Dr. Goldschmidt that the σ phase could be obtained by decarburizing the $Cr_{23}C_6$ carbide in its free state, but this direct transformation does not seem very probable in duplex Cr–Ni steels. It has been observed by several authors, e.g. Morley and Kirkby,[6] that in austenitic Cr–Ni steels, the amount of $Cr_{23}C_6$ decreases as σ begins to precipitate. However, this is commonly considered to be a resolution of $Cr_{23}C_6$ in austenite when the latter is impoverished in chromium as a consequence of the formation of σ.

It is known for certain that chromium has a weaker affinity for carbon than has vanadium, but the comparative strength of the carbon affinity of chromium, molybdenum, and tungsten is still uncertain.

Among the many interesting questions raised by Dr. Cina, that about the possibility of nitrogen pick-up during the high-temperature treatment deserves to be discussed first, because this concerns all five parts of my paper. I regret that I have not used an inert gas instead of nitrogen so that this possibility could be dismissed, and that no nitrogen analysis has been made on any of the steels before and after the high-temperature treatment. Perhaps it is not misleading to maintain that the nitrogen pick-up in molybdenum and tungsten steels cannot be very great, because the nitrides of these elements dissociate quickly above 1200° C. In chromium and vanadium steels, however, this pick-up might be appreciable and would affect the δ to γ ratio. However, it should be pointed out that no needle-like nitride has been observed under the microscope in the steel specimens. Theoretically, it would be possible to obtain a eutectoid of γ and an alloy nitride from δ.

In Part I, I found that the Fe_3Mo_3C carbide disappears at a lower temperature in δ-ferrite than in austenite, and considered that this is due to the higher solubility of molybdenum in δ-ferrite. On the other hand, Dr. Cina suggests that the higher rate of diffusion of carbon in ferrite than in austenite may account for the fact that the alloy carbide disappears first in δ-ferrite. This is the same explanation as Dr. Nehrenberg has given earlier for a similar phenomenon observed in carbon and low-alloy steels (*see* Dr. Nehrenberg's contribution). At present it is difficult to ascertain which of these factors is more important. Fortunately they are complementary rather than contradictory.

The intermediate phase Fe_7Mo_6 is fairly stable in dilute acids and can be satisfactorily extracted from iron-molybdenum alloys. I have not tried to determine by X-ray the identity of the lamellar phase in δ-eutectoid in the solid sample mainly because the amount is not large, so that the identification by X-rays would be less sensitive than by using the extracted residue.

In Part III, I identified the small particles, in Fig. 4 as austenite because they were attacked by Vilella's reagent. If they were carbide particles as Dr. Cina claims, they would be attacked less than δ-ferrite and would appear in relief in Fig. 4*b*. This is certainly not the case. After a less severe quenching, these particles grew to larger dimensions as shown in Fig. 5, and could be positively identified as austenite.

Dr. Cina asks why these austenite dots do not appear in Figs. 8, 9, and 10 in the specimens quenched to 800° C and held for 10 min at this temperature, when the knee of the $\delta \rightarrow \gamma$ transformation curve is at 950° C. From the study of the transformation of austenite in low-alloy steels we know that the continuous transformation curve lies at a much lower temperature than the isothermal transformation curve. The same must also apply to the transformation of δ-ferrite, and it is not impossible that during water quenching, the cooling curve of the steel specimen cuts the knee of the $\delta \rightarrow \gamma$ transformation curve below 800° C.

Dr. Cina mentions his observation of the precipitation of chromium carbide in ferrite in plain 20% and 30% chromium irons. In the absence of 5% Ni, Dr. Cina's ferrite must be very stable and the formation of austenite

must be very difficult, if at all possible (this will depend mainly upon the carbon-content of the chromium irons).

As can be seen from Fig. 1, δ-eutectoid will be present after one hour at 1000° C, though Fig. 6 shows only the presence of pro-eutectoid austenite. Owing to the low carbon content (0·079%) of the steel used in Part III, the amount of δ-eutectoid was very small, and it occurred mostly along the ferrite grain boundaries (*see* Fig. 8*b*). Figure 6 shows the selected part in a ferrite grain where δ-eutectoid does not exist. I regret that this has not been clearly pointed out in the text.

In Part IV, using an 18/10/3 instead of an 18/8/3 Cr–Ni–Mo steel, I was forced to heat the steel to 1350° C instead of to 1050° C to obtain 20% δ-ferrite. This shows that a small difference in chemical composition may have a very large effect on the constitution of the steel. According to Dr. Cina, the difference in heating temperature will have a very large effect on the composition of the phases and therefore on the mechanism and kinetics of the transformation of δ-ferrite. This shows the complex nature of the high-alloy steels and the danger of applying the observations and conclusions gained from one steel to another with a slightly different composition.

Dealing with the various transformation in high-alloy steels, I put more emphasis on the slow-diffusing alloy elements than on carbon, while Dr. Cina seems to lay more stress on the latter. In my opinion, the supply of the alloy element is more important than that of carbon for the precipitation of an alloy carbide. That this point of view seems to be correct can be seen from the fact that the formation of δ-eutectoid occurs at a temperature about 400° C higher than that of pearlite, i.e. at a temperature at which the diffusion rate of an alloying element in ferrite is about the same as that of carbon in austenite. As the temperature is lowered the δ-ferrite in a low-carbon high-alloy steel may become supersaturated with respect to the alloy element though not necessarily with respect to carbon. In spite of the low carbon content of δ-ferrite, an alloy carbide may still precipitate in it; the supply of the quick diffusing carbon is only a factor of secondary importance, and can be maintained by the so-called long-range diffusion from the nearby carbon-rich austenite, as is the case with the 8% Mo steel in Part I.

However, the formation of δ-eutectoid can also occur independently without the co-operation of a co-existing austenite, as has been shown in Part III, so that the long-range diffusion of carbon is not a necessary condition for its formation. Hence the objection raised by Dr. Cina and Dr. Nehrenberg about the parallelism of the pearlite and δ-eutectoid reactions may be met.

I agree with Dr. Cina that the surface relief effect of the $\delta \rightarrow \gamma'$ transformation shown in Fig. 6 of Part IV indicates a coherent transformation mechanism similar to that of bainite. I have not yet made any experiment on heating a stable austenite in vacuum to see whether there will be any surface effect.

Professor Hultgren points out the paradoxical phenomenon that in the 18/4/1 W–Cr–V high-speed steel (Part II) the eutectoid reaction $\delta \rightarrow \gamma + \eta$ occurs instead of the peritectoid reaction $\delta + \gamma \rightarrow \eta$ though the latter is predicted from Takeda's equilibrium diagram for the Fe–W–C system. In the footnote on p. 224 (Part V), I questioned the accuracy of Takeda's diagram because this requires a peritectoid reaction between two iron phases (δ and γ) to form an alloy carbide (η) as the only product. It is gratifying to learn that Prof. Hultgren has offered another explanation to the above mentioned apparent discrepancy. The character of a binary reaction in a ternary system, whether it is eutectoid or peritectoid is extremely complicated and uncertain, and this point has been discussed in great length in Part V.

I welcome Dr. Nehrenberg's statement that his own observations agree essentially with mine concerning the metallography of δ-ferrite in general, and the absence of veining in oil-quenched high-chromium steels in particular. In reply to Dr. Cina I have already touched on some of the points discussed by Dr. Nehrenberg.

I admit that the transformation front of δ-eutectoid is usually very smooth, as is shown in Fig. 12*a* (Part I) and in Fig. 16*a* and *b* of the paper by Nehrenberg and Lillys.[3] The explanation Dr. Nehrenberg offered for the concave appearance of δ in a eutectoid formed during continuous cooling (Fig. 7*b*, Part I) is novel, and his suggestion of further investigation using isothermal transformed samples deserves special attention. However, I do not agree with Dr. Nehrenberg that Fig. 7*a* (Part III) fails to show any conclusive evidence that the carbide is the leading phase of the formation of δ-eutectoid. Those areas marked with arrows show the early stage of δ-eutectoid formation. In the δ-eutectoid near the centre of the bottom of Fig. 7*a* it can be seen that this has been nucleated by an alloy carbide.

REFERENCES

1. A. E. NEHRENBERG: *Trans. Amer. Inst. Mech. Eng.*, 1950, vol. 188, pp. 162–174.
2. A. HULTGREN: *Ibid*, 1950, vol. 188, p. 1377.
3. A. E. NEHRENBERG and P. LILLYS: *Trans. Amer. Soc. Metals*, 1954, vol. 46, pp. 1176–1213.
4. J. I. MORLEY and H. W. KIRKBY: *J. Iron Steel Inst.*, 1952, vol. 172, pp. 129–142.
5. A. WESTGREN: *Jernkontorets Ann.*, 1933, vol. 117, pp. 1–14.

DISCUSSION ON SILICEOUS AND TITANIUM-BEARING INCLUSIONS IN IRON

This discussion was based on the following papers (dates of publication in the *Journal* are given in parenthesis): **"A Microscopical Examination of Samples of Iron containing Siliceous Inclusions,"** by R. E. Lismer and F. B. Pickering (1955, vol. 179, Feb. pp. 159–160). **"A Microscopical Examination of Samples of Iron containing Titanium-bearing Inclusions,"** by F. B. Pickering, (1955, vol. 181, October, pp. 147–149).

Mr. **F. B. Pickering** (Research and Development Department, United Steel Companies Ltd.) presented both papers.

Mr. **G. E. Speight** (RTSC Laboratories): As I have been associated with the B.I.S.R.A. Group which has been interested in this work, I should like to refer to the circumstances leading to these investigations and the results which have been presented.

During the last few years, Evans and Sloman at the National Physical Laboratories have carried out careful studies of deoxidation reactions and of the deoxidation products arising from the use of manganese, aluminium, silicon, and titanium. Their work involved the preparation of iron melts, treated with deoxidants to provide a range of deoxidation products which were then studied by chemical methods, X-rays, and by the optical microscope. They were able to identify, and add considerably to our knowledge of, non-metallic inclusions which are found in commercial steels, besides some which had not been suspected. As the Solid Steel Study

Group was at the same time engaged in the study and classification of non-metallic inclusions it was decided that the works of Evans and Sloman should be supplemented by further metallographic studies on the same samples, in order to establish the characteristics of these inclusions and their response to various chemical treatments and etching techniques. It was thought that the detailed observations now recorded would be of service to other workers and would assist in the clarification of the present nomenclature for non-metallic inclusions.

There is little doubt that the work of the present authors, together with that of Evans and Sloman, will achieve this. A concise account of the characteristics of inclusions arising in deoxidation processes has been recorded, together with excellent photomicrographs which will be very useful to metallographers in routine examinations of commercial materials. The silicon deoxidation series provides examples of the full range of deoxidation products from wüstite to glassy silicates, and because of their reactivity to various chemical reagents and etching media, it has been possible to make a detailed study of these inclusions. The same extensive examination has not been possible with the titanium deoxidation series because the inclusions are more refractory.

There are perhaps several directions in which the subject matter might have been extended, not necessarily to increase the value of the papers, but to widen their interest for the non specialist. The samples were prepared from small melts, i.e. 400g, and it is possible that in such melts the conditions at freezing etc. are not the same as in larger commercial ingots. How would this difference affect the size, shape, and constitution of the deoxidation inclusions? Further, most commercial materials have to be examined in the wrought state. How, therefore, are the inclusions modified by heat treatments and deformation in the solid state? How would turbulence and gas evolution in casting, as in rimming steels, affect the shape and constitution of inclusions? It may be that comparable examinations of a few typical samples of rimming, balanced, silicon-killed steels etc., both in the as-cast and wrought conditions, might provide further useful quantitative data in relation to the above questions. Perhaps the authors might consider the extension of their work on these lines.

While this work has been confined to what may be regarded as the more common techniques for the study of inclusions, newer techniques, e.g. electron microscopy, microbeam X-ray, etc., are being developed and they may ultimately prove useful in the study of non-metallic inclusions. Work on these lines is proceeding and as most of these valuable samples are still available, the Gases and Non-Metallics Group would welcome assistance from anyone who has specialized in the application of these newer techniques.

Dr. **B. A. Bilby** (Sheffield University): Mr. Pickering said that the appearance of a cross and concentric rings in examining some of these glassy silicate particles was due to a geometrical effect. I always thought that this was associated with anisotropic optical qualities. Would he enlarge on this point?

Mr. **V. Thomas** (RTSC Laboratories): With respect to the siliceous inclusions, particularly fayalite, there appears to be a discrepancy between the authors' results and those of the American workers Scheil, Baeyertz, and Vilella.[1] The latter states that fayalite is translucent and shows strong birefringence, whereas the authors of the present paper state that fayalite is opaque.

Mr. **B. R. Jackson** (Stewarts and Lloyds Research Laboratories): With microbeam X-ray technique, could a very fine beam hit a single inclusion and so aid identification?

Mr. **T. H. Arnold** (Hadfields, Ltd.): Is it not a fact that we are unable to identify glassy inclusions by X-ray or electron diffraction methods? These are only two of a number of methods used in attempts to identify inclusions. Each method is limited in its scope and it is necessary therefore to utilize more than one method.

Mr. **L. Pryce** (United Steel Companies Ltd.): Have the authors any views on why twinning is obtained in αTi_2O_3 inclusions with ingots which apparently have had no cold work, hot work, or heat treatment?

Mr. **Thomas**: Reverting to my previous question, personally I do not know whether fayalite is a translucent opaque mineral but I am inclined to support the present authors' findings. The inclusions, essentially wüstite, in the melts containing the least amount of silicon are well illustrated; the SiO_2–FeO equilibrium diagram shows a eutectic between wüstite and fayalite, and with increasing additions of silicon the second phase appears. As illustrated by the authors, this second phase, which is opaque, must be the fayalite constituent of the eutectic mixture. With further additions of silicon, the proportion of fayalite on the non-metallic particles would be expected to increase at the expense of the wüstite. The evidence obtained by the authors that fayalite is opaque and black under polarized light seemed to be more positive than that of the American workers who stated that this mineral was translucent.

Referring to the peculiar bands in Ti_2O_3 which the authors have illustrated, it may be of interest to note that the cast structure of ingots of germanium shows heavy twinning. I have no knowledge of the crystal systems of germanium or Ti_2O_3 and I make the observation that twinned structures have been seen in cast minerals.

Mr. **Arnold**: Twinning as seen under the microscope can arise from the work done in preparing the specimen as I know from experience with manganese steel.

Mr. **Jackson**: Had the authors considered injecting known non-metallic inclusions into vacuum melts in order to establish identification standards?

AUTHOR'S REPLY

Mr. **Pickering**: Mr. Speight has touched upon a very important subject in raising the question of whether inclusions in small ingots were representative of those in larger ingots. It should be borne in mind, however, that the degree of heterogeneity would increase with ingot size, as would the size of any particular inclusion.

Mr. Speight was correct in stating that hot deformation could alter the appearance of an inclusion, and a little preliminary work has already been done on the effect of hot work. The plasticity of the inclusions was the main variable, together with the degree to which they could be deformed before fracture occurred. Both these features affected the breakdown and dissemination of inclusions throughout the steel, and it had been suggested that such effects could influence the transverse mechanical properties in large forgings. Preliminary work had already indicated the mechanism by which silicate inclusions could be disseminated throughout the steel. Heat treatment had not been observed to have an appreciable effect on the shape of an inclusion, but might cause some types to undergo a solid state reaction, e.g. formation of magnetite from wüstite.

The effect of turbulence would be expected to be most marked on idiomorphic inclusions which were also brittle. In rimming steels the inclusions would mainly be of the iron-manganese-oxide type which form as spherical particles and would not be expected to break up.

The cross and concentric circle effect under polarized light mentioned by Dr. Bilby, was mainly a geometrical effect which did not depend on any anistropic properties of the inclusion. The occurrence of this phenomenon which, incidentally, can sometimes be seen in a pit from

which an inclusion has fallen out, has been discussed in detail by R. W. Dayton.[2] He states that the concentric circles are due to intensity variations not connected with polarization phenomena. Polarized light merely enables these reflections to be observed by cutting out the surface reflections.

I do not think there is any real discrepancy between our observations and those mentioned by Mr. Thomas. In a more recent publication, Baeyertz[3] has described fayalite as dark grey under reflected light, with internal reflections. In the very few crystalline fayalite inclusions seen, the internal reflections were not observed, perhaps because of the shape of the inclusions, and their transparency was so low that under polarized light no effect could be obtained.

In reply to Mr. Jackson's question, it is theoretically possible to irradiate a single inclusion by an X-ray microbeam, but the volume of the inclusion with respect to the total volume of metal irradiated should always be rather large. The exposure time is necessarily long, but we have managed to obtain a diffraction pattern from a segregate of alumina inclusions in a thin slice of material polished down to 0·002 in. thick. We have not obtained any results from a single inclusion, and as one such inclusion could well be a single crystal, further complications can arise in obtaining a diffraction pattern.

Mr. Arnold is correct in stating that X-ray or electron diffraction techniques cannot identify non-crystalline inclusions but micro-radiographic and X-ray fluorescent techniques can give useful information in assisting in the identification of inclusions. Electron microscopy, using replicas, might also be useful in observing fine dispersions of a second phase within an inclusion.

There is a definite probability that the inclusions might have been cold-worked during preparation. The bands observed across the Ti_3O_5 inclusions when Ti_3O_5 was present may have been true twinning effect due to either polishing, casting stresses, or stresses introduced during gripping the specimens whilst cutting the ingots.

Finally, to reply to Mr. Jackson's question whether the approach of injecting non-metallic inclusions into vacuum melts had been used, I prefer to use naturally occurring inclusions rather than synthetic ones. There is nothing wrong in the principle of synthetic inclusions except that it is not possible to see them in the as-cast state, which can be most informative in providing characteristic shapes for identification. Such characteristic shapes are, of course, lost when synthetic inclusions are used, especially if they are introduced into the material by deformation in the solid state.

REFERENCES

1. M. A. Scheil, M. Baeyertz, and J. R. Vilella: *Trans. Amer. Soc. Metals*, 1939, vol. 27, pp. 479–504; Metals Handbook, pp. 445–452, 1945, Cleveland, A.S.M.
2. R. W. Dayton: *Metals Technology*, 1935, January, T.P. 593.
3. M. Baeyertz: "Non-metallic Inclusions in Steel," 1947, Cleveland, A.S.M.

DISCUSSION ON STRAIN AGEING

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

"The Strain Ageing of Alpha Iron," *by W. R. Thomas and G. M. Leak* (1955, vol. 180, June, pp. 155–161).

"The Strain Ageing of Pure Iron," *by B. Jones and R. A. Owen-Barnett* (1955, vol. 180, May, pp. 20–23).

The papers were presented by Dr. **G. M. Leak** (B.I.S.R.A., Sheffield) and Mr. **R. A. Owen-Barnett** (Whitehead Iron and Steel Co., Ltd.).

Dr. **B. A. Bilby** (Sheffield University): In our paper[3] on the strain ageing process, Dr. Cottrell and I tried to seize on its essential features, making a number of simplifying assumptions so that some quantitative predictions became possible. Many further experiments are being done, and complications and discrepancies being revealed. It is now appropriate to reconsider and to develop the theory in the light of the new results.

The paper by Jones and Owen-Barnett is an interesting addition to the series from their laboratory on the strain-ageing process. The marked difference in ageing times between specimens which have been temper-rolled (or overstrained in torsion) and those which have been subjected to tensile overstrain is, at first sight, extraordinary. It is necessary, however, to distinguish between the effect of certain elements present in commercial steels, particularly the aluminium in aluminium-killed steel, and that of the temper-rolling process. Both the latter, with the non-uniform stresses which it produces in the sheet, and the aluminium, may have an influence on the ageing, and experiments to separate the two are important. There is now general agreement on the theory of why the ageing time is much longer after temper-rolling; the phenomenon is essentially a manifestation of the Bauschinger effect. The deformation process producing the overstrain leads to inhomogeneous stresses. The strain-ageing process, in terms of the migration of the carbon and nitrogen to dislocations, is rapid, but, when the material is subsequently tested, because of the distribution of stress concentrations, the yield phenomena are greatly reduced or suppressed, as when a badly aligned or notched specimen is tested in tension. This simple explanation is, however, not the whole story, for, if it were, the activation energy for the return of the yield phenomena after temper-rolling should be that for the removal of these inhomogeneous stresses, i.e. similar to that for the recovery of iron. Recently, however, Dr. Hundy has told me of evidence which suggests that the activation energy is nearer to that for carbon diffusion. It would be interesting to know if the authors have tried to estimate this activation energy, and with what result. In this connection it is important to distinguish between experiments which follow the removal of carbon or nitrogen from the lattice, and those which follow some mechanical property which depends on their accumulation at dislocations or elsewhere. Would it be possible to follow this removal directly after torsion or temper-rolling, or after some other deformation producing marked inhomogeneity of stress?

The valuable experiments of Thomas and Leak do follow the normal ageing process by observing this removal by internal friction measurements. The authors are to be congratulated on their careful attempt to separate the effects of carbon and of nitrogen. The central conclusion of the paper is the confirmation of Dahl and Lücke's experiments,[4] which show that the

$t^{2/3}$ law, predicted by the simple theory,[3] holds until there are many more carbon atoms per atom plane of the dislocation line than one would think necessary merely to relieve the elastic stresses. The persistence of the $t^{2/3}$ law has also been found by Harper,[5] and is surprising,[6] because the simplifying assumptions made in the theory make it properly applicable only to the initial stages of ageing. In particular, the effect of diffusion in modifying the concentration gradients set up during the ageing process, and the decrease in the attractive force of the dislocation for other solute atoms as the atmosphere forms (saturation effect) were ignored. Saturation slows the ageing rate, and is probably a second order effect; diffusion, under the conditions expected in iron alloys,[6] increases the ageing rate, so that a possible explanation of the persistence of the $t^{2/3}$ law is that these effects in part compensate one another. A third simplifying assumption of the original theory was that only the hydrostatic interaction was considered. The following argument, due to Cottrell, shows that, while the model of the atom movements may be modified by the inclusion of interactions allowing for asymmetric distortion, the $t^{2/3}$ law will remain, since the dislocation stresses and therefore the interaction energy vary as r^{-1}; thus the drift velocity of the solute atom varies as r^{-2}, and the time taken by an atom at a distance r from the dislocation to reach it varies as r^3. Since initially the number of atoms between o and r is proportional to r^2, the $t^{2/3}$ law follows.

In view of these simplifying assumptions, it must be remembered that the deduction of these large atmosphere densities is not entirely experimental, because the simple theory is used in the estimation of L, the total length of dislocation line per unit volume. It is, therefore, possible that a refined theory might still give the same time law, but with different constants for the slope of the straight-line plots made and, therefore, with different values of L. The authors' greatest atmosphere densities are only about five times too large, and those of Dahl and Lücke fifty times; the latters' estimated dislocation densities are correspondingly lower. If these high densities are accepted, however, it is necessary to consider processes other than that of the simple relief of elastic stresses. Before discussing these, another interesting feature of the authors' results should be noted; they followed the ageing process both by internal friction measurements and by measurements of the increase of the limit of proportionality and the upper and lower yield points with ageing time. Now, although they show that the techniques are complementary (e.g. when the internal friction measurements indicate that solute atoms are no longer being removed from solution, the yield point ceases to increase), they do not comment on the interesting fact that, while the $t^{2/3}$ law is valid up to $q \simeq 0{\cdot}6$ and the original theory suggests that the dislocations should be saturated when $q \simeq 0{\cdot}2$, in fact, even at $q \simeq 0{\cdot}6$, their Fig. 4 shows that the yield point has by this time only undergone about *half* its final increase. What then is happening to increase the yield point for the remainder of the ageing time ?

The authors suggest that, during the later stages of ageing, atoms in the *outer* atmosphere (where their binding energy is less than that in a precipitate in the matrix) are being removed to form precipitates. They argue that, since the atmosphere will again be replenished, this process might explain the persistence of the $t^{2/3}$ law. I understand from the introduction just given by Dr. Leak that he does not picture these precipitates as finely dispersed in the matrix. However, thinking of the authors' description of 'precipitation removing atoms from the dislocation,' it occurred to Professor Quarrell and me to plot their quench-ageing results against $t^{2/3}$ and, using rough measurements from the graphs, they seemed to fit quite well. Have the authors made such a plot with the accurate data, and have they any comments on the time law of quench-ageing ? From their results there seems to be no incubation period for quench ageing, in contrast to some other reports. One consequence of the suggestion that precipitates form during the strain-ageing process is that their hardening effect should be increasingly apparent on repeated straining and ageing; such a hardening must, of course, be distinguished from that due to the work-hardening associated with the straining, and in zinc,[7] where normal recovery occurs at the ageing temperature, is absent. Experiments on repeated straining and ageing might distinguish true from subcritical precipitation, stable only in the presence of lattice distortion. Have the authors carried out such experiments ?

An alternative explanation of the persistence of the $t^{2/3}$ law suggests itself when the problem is examined in three dimensions rather than two. At an early stage in the ageing process (e.g. at about two atoms per atom plane) the dislocations become saturated. Then, at certain points along the dislocation line, small nuclei for precipitates begin to form. These are then fed preferentially by carbon (or nitrogen) atoms moving *along the dislocation lines*, since these provide paths for rapid diffusion.[8] New vacant places along the line *at the position of maximum binding* will thus appear, and will be filled again by solute atoms drawn from the matrix, as in the early stages of ageing. For this process the $t^{2/3}$ law might again be expected, as the solute atoms are being removed from the matrix in a way essentially similar to that in the initial stages of ageing. This situation could continue for a long time, until perhaps, competition between dislocations for solute atoms becomes important. The solute atoms are not in this picture leaving the outer atmosphere (for which process it is not obvious that a $t^{2/3}$ law is to be expected) but are moving along the dislocation to neighbouring sites of high binding energy until they reach a site where their binding energy is even greater (because of chemical factors) than that of a site of maximum purely elastic binding. The precipitates will again be localized along the dislocation, and may in fact be sub-critical and redissolve when the dislocations are removed from them in a subsequent straining. Alternatively, they may not, and so give a cumulative hardening on repeated straining and ageing. With a slight elaboration, this mechanism could also account for similar precipitation at grain boundaries, the dislocations formed during the straining acting as a system of subgranular channels, collecting solute atoms and piping them rapidly to precipitation sites.

Dr. **Brynmor Jones** (Whitehead Iron and Steel Co., Ltd.): The paper by Thomas and Leak represents a well-planned research on specially purified iron to which known amounts of carbon and nitrogen have been added separately, and the rates of strain ageing after tensile straining have been determined at various temperatures between 24° and 67° C. The estimated activation energies for strain ageing confirm the results obtained by previous research workers; e.g. Wert in 1950, in some work published in the *J. Appl. Phys.* of that year, found that the activation energy of carbon in iron was 20·1 kcal/mole and that the activation energy for the diffusion of nitrogen was 18·2 kcal/mole, against 20·4 and 18·0 respectively found by the present authors; these are very close agreements.

In both the papers now under discussion, the basic material is pure iron, but a better term is high-purity iron, which was further purified in hydrogen. As it has

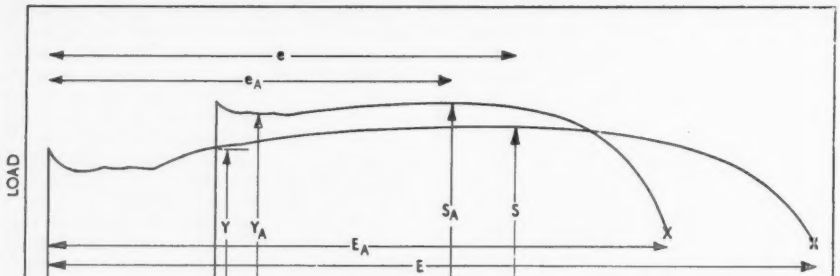


Fig. A—Effect of strain ageing on load/extension curve for iron containing 0·0035% C and 0·0025% N

been shown that the small amounts of carbon and nitrogen in these irons cause appreciable strain ageing, it would have been of great interest to find the individual effects of these small amounts of the elements, i.e. the relative effects of 0·003% carbon in the absence of nitrogen, and of 0·0014% nitrogen in the absence of carbon, on strain ageing, as the iron is supersaturated in respect of each element, carbon and nitrogen.

I am prompted to refer to this matter because the authors state on p. 157 that homogeneous specimens of iron–nitrogen alloys were actually made with nitrogen contents varying from 0·001% to 0·030%. It may well be that 0·001% or less of nitrogen alone will cause appreciable strain ageing in iron, and it would have been most interesting to have had confirmation of this. The difference between the effects of carbon and nitrogen almost certainly depends on the difference in the solubilities of these elements in iron. In the nitrogen-bearing irons, the ageing tests have been carried out on iron containing 0·015% and 0·029% of nitrogen. These amounts are much greater than are present even in high-nitrogen Bessemer steels. Such steels would require denitrogenizing to make them usable for many purposes. Steels made by the O.H. and by modern improved Bessemer processes contain less than 0·006% of nitrogen. It is appreciated that it may be of interest to consider the effects of similar amounts of nitrogen and carbon, such as 0·015% of each; but it is accepted that this amount of nitrogen has a more drastic effect on strain ageing and other properties than a similar amount of carbon.

With reference to the treatment of $\frac{1}{8}$-in. iron wire in flowing wet hydrogen for five days, why was such a prolonged period necessary and did the authors find that this treatment affected the grain boundaries near the surface, causing intercrystalline weakness? Moreover, was the purified wire heat-treated after drawing down to fine wire, before the introduction of nitrogen and carbon into the specimens at a temperature of 700° C? We have found that heavily cold-worked iron does not recrystallize completely at 700° C, which prompts me to ask whether an even grain size was imparted to the iron-nitrogen and iron–carbon specimens before 7% tensile straining, as I understand that internal friction measurements are influenced by grain size.

A most interesting confirmation of the mechanism of strain ageing is given in Fig. 4, which shows that measurement of ageing by the determination of the limit of proportionality and yield-point and the measurement of internal friction are in close agreement. These results show that ageing is caused by the movement of solute atoms from free solution towards the dislocations. The authors state that precipitation must occur on ageing; this confirms the explanation given by myself and Owen-Barnett last year.[2]

In the past, metallurgists have explained the mechanism of strain ageing as being due to precipitation, such as precipitation on slip-planes, but later they apparently wished to avoid the term and referred to a finely-dispersed phase or to an intermediate stage between a true solution and the separation of a distinct phase which agglomerated in the final stage of ageing. Until recently, advocates of the dislocation theory have also avoided the word 'precipitation', but they have now decided to use it again and to combine it with dislocations. It would appear, therefore, that the older metallurgical explanation of ageing is again being partly accepted.

Dr. **B. B. Hundy** (Steel, Peech and Tozer): These two papers, both of which deal with B.I.S.R.A. *AH* pure iron, add to our knowledge of the phenomena of strain ageing. The careful experimental work of Thomas and Leak, confirms once again the validity of the dislocation theory of strain ageing. This is one of the real triumphs of the general dislocation theory. I should like to comment on some of the detailed results which the authors present. First, referring to Fig. 1, I find it interesting that the rates of quench ageing of the carbon–iron and nitrogen–iron alloys, as shown by the curves for ageing at 98° and 109° C, are fairly similar. Although only about 10° C apart, they fall more or less in line with each other whereas the curves for strain ageing at similar temperatures in (*c*) and (*d*) show that the nitrogen–iron alloy ages much more rapidly than the carbon–iron alloy. Have the authors anything to add to this?

My next point concerns Figs. 2 and 5, which give the authors' strain-ageing results. Why does the nitrogen–iron alloy apparently cease strain ageing at a value of $q = 0{\cdot}7$ (the authors call it $1 - C$ and not q), whereas the carbon–iron alloy in Fig. 5 apparently goes on strain ageing to a value of $q = 0{\cdot}9$–$1{\cdot}0$? Is this a reflection of the higher solid solubility of the nitrogen in iron?

With regard to the variation of dislocation density with carbon content after tensile straining, the authors show that an increase in the carbon content increases the dislocation density, i.e. the rate of work-hardening is greater. How would the distribution of the carbon affect this? If the specimens were quench-aged to bring the carbon out as a precipitate, would the rate of work-hardening be higher or lower? Also, how is the yield stress affected by the mode of distribution of the carbon.

Turning now to the paper by Jones and Owen-Barnett, I should like to ask what is the difference between the steels used in the present paper, *AHP6* and *AHP10*, and that described in their previous paper, which they called *BS*. There does not seem to be much difference in the yield-point but, in their previous work, the authors did not seem to get any loss of ductility or increase in tensile strength on strain ageing; such strain-age hardening is dependent primarily on the

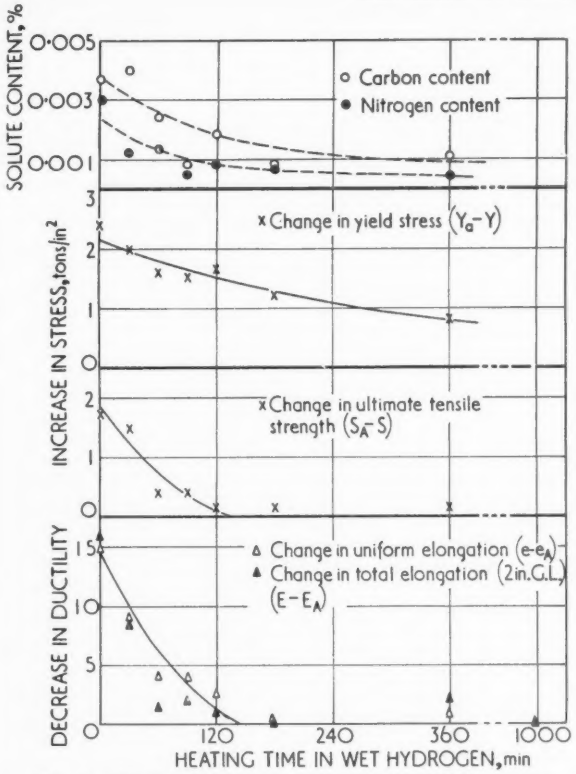


Fig. B—Effect of heating in wet hydrogen at 800° C on the change in properties due to straining 10% and ageing fully

nitrogen content of the steel; the lower the nitrogen content is, the smaller is the fall in ductility on strain ageing and the present work seems to be in line with this: steel *AHP10* contains 0·0016% nitrogen and shows a greater strain-age hardening effect than steel *AHP6*, which contains only 0·0011% nitrogen. The authors' earlier work on an O.H. steel with 0·005% nitrogen showed an even greater strain-age hardening effect; this suggests that the nitrogen content of the *BS* batch was probably even lower than 0·001%.

In connection with the authors' work on the hydrogen treatment of the pure iron, I should like to show some of my own results, which indicate the effect of a reduction of the carbon and nitrogen content on strain ageing and strain-age hardening. We used the B.I.S.R.A. *AH* iron treated in various ways, and Fig. *A* shows the results obtained from this steel in the annealed condition after straining 10% and ageing overnight at about 100° C. Specimens were heated in wet hydrogen at about 800° C for varying lengths of time and were then homogenized at about 700° C and the strain-ageing tests were repeated; Fig. *B* shows the results. The chemical compositions of the nitrogen and carbon contents are given, though, at such low figures as 0·001%, etc., the results of the chemical analyses cannot be expected to be exactly correct. As the heating time in wet hydrogen is increased, it is found that the strain-age hardening effect (the change in the ductility and tensile strength on ageing) vanishes after heating for about 2 h, while the strain-ageing effect (the return of the yield point) only vanishes after a further 8 h heating; after this time of heating, the steel still has an initial yield point due to the final traces of carbon and nitrogen. Dr. Leak and Dr. Bilby have already pointed out how small precipitates of nitride will form at the dislocations as ageing proceeds and it is my contention that these cause the fall in ductility and rise in tensile strength on strain ageing.[9] When there is sufficient nitrogen present to lock the dislocations, but not enough to form a precipitate, strain ageing can take place but not strain-age hardening. This occurs with de-nitriding times of 2–10 h. The strain-age hardening effect probably vanishes at nitrogen contents below 0·005% N.

Dr. Bilby asked whether anyone had done any repeated strain-ageing tests. The results of some tests of this sort are shown in Fig. *C* and Table *A*. Mild-steel wire was drawn 1%, tested, aged, tested, drawn a further 2·2%, tested, aged, tested, etc., up to a total reduction of 6%. Other samples were drawn without ageing and still more were drawn to reductions of 3·2, 4·4, and 6·2% and were aged after this. The results show that repeated strain ageing had a greater effect on the mechanical properties than did drawing to the required reduction with only a final ageing treatment. These results can be explained in terms of the increased rate of work-hardening found after a specimen has been strain aged.

Professor **A. G. Quarrell** (Sheffield University): If there is precipitation of about 10 atoms per atomic plane cut by the dislocation, it would seem that the precipitate must be of such a size as to make possible its detection by direct methods. All the methods discussed this morning are really indirect methods, by which we deduce what is happening from other measurements. The evidence which has been put forward suggests that the use of direct methods would enable us to detect this pseudo-precipitate, if it does form.

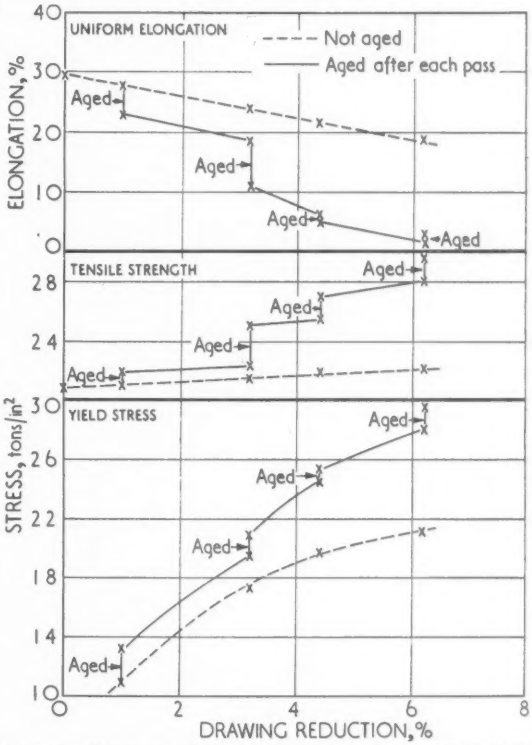


Fig. C—Effect of repeated strain ageing on mechanical properties of mild-steel wire. Ageing treatment 1 h at 135° C (each point shown is a mean of 6 experimental values)

Table A EFFECT OF DIFFERENT SEQUENCES OF AGEING ON THE MECHANICAL PROPERTIES OF DRAWN WIRE

Drawing Sequence	Ageing after Each Pass		Ageing after Final Pass Only	
	Elongation	U.T.S., lb/in²	Elongation	U.T.S., lb/in²
3·2% (1% plus 2·2%)	11%	25	14%	24
4·4% (1% plus 2·2% plus 1·2%)	5%	26·9	11%	25·3
6·2% (1% plus 1·2% plus 1·8%)	2·5%	29·5	9%	26·5

AUTHORS' REPLIES

Dr. **G. M. Leak :** Dr. Bilby has answered most of his own comments in terms with which we agree. With regard to the important point of precipitation, which Professor Quarrell also raised, there does not seem to be much evidence in the case of iron–carbon or iron–nitrogen of precipitation at dislocations. Dr. Jack has produced a certain amount of evidence, including some photographs of a strain-aged iron–carbon specimen, which unfortunately also contained nitrogen, and there is some evidence of large precipitation along the slip-planes; but whether this is in fact a result of precipitation caused by movement of solute atoms along the dislocations I do not know. Whether there is any precipitation which can be found and observed is a point which requires much more investigation.

I agree with Dr. Bilby that there is a doubt as to whether the theory will be able to differentiate between 2 and 10 atoms. It is a question of dislocation density.

Dr. Jones said that we had used specimens containing more nitrogen than would normally be found in a commercial steel, and this is true. We have also carried out some ageing measurements on materials containing small amounts of nitrogen, down to 0·001% or 0·002%, and this becomes extremely difficult. By the internal friction method, one follows the decrease in height of the internal friction peak, and we would put the limit of measurement at about 0·0005%. Any measurements which we made on material containing 0·001–0·002% would give great inaccuracy, therefore, and the scatter would be so large that the results would not be very valid. We have done some measurements, as I say, but because of the scatter which we obtained we have not included the pictures in the paper. The ageing still follows the same sort of law to be expected by extrapolation from higher nitrogen and carbon contents.

With regard to activation energies, Dr. Jones points out that our figures agree with some previously published. This, I think, was fortuitous at the time. We did not put great weight on the determination of 20·4 kcal because that is the figure which we obtained. The experiments are not carried out to determine activation energy, but the figure is probably within ± 2 kcal.

So far as the treatment of the specimens is concerned, the internal friction method, provided the texture of the specimens is not changed, can be applied to specimens in almost any condition. We investigated the effect of homogenizing treatments and found that where we had to homogenize our specimens, after nitriding and carburizing, and treated specimens up to about 1000° C, this made no difference to the curves obtained by internal friction measurements. Whether our specimens had been fully recrystallized or sufficiently recrystallized for the ageing to carry on at the correct rate made no difference at the temperature at which we heated them. Internal friction methods are influenced by grain size and texture. We checked the texture at various times during our measurements, and our specimens did not seem to change in texture. We checked too the proportionality between the internal friction measurements and the chemical composition of the specimens.

Dr. Hundy made a point about the ageing rates being almost identical. I am not sure of the answer to this. We know that quench ageing in iron–carbon goes at a much faster rate than in iron–nitrogen, but presumably the supersaturation effect and the difference in temperature between 98° C and 109° C make an appreciable difference to the diffusion rate, particularly when these measurements are plotted on a log scale.

His other point was that the iron–nitrogen specimens appear to stop ageing at a value for q of 0·7, whereas the iron–carbon specimens carried on to almost complete ageing. That is not due to the solubility of nitrogen, because at these temperatures even the solubility of nitrogen is very low. There is a difference in time-scale in the two graphs and Fe–N specimens will go up to $q = 0·9$ and more, almost to complete ageing.

Mr. **R. A. Owen-Barnett:** Dr. Bilby brought to our attention the difference in ageing time of temper-rolled and tensile-strained material. We have not brought the point out in this paper, but it was well brought out in the earlier paper on the tensile straining of mild steel. The reason was the shortage of pure iron available to us. We would have liked to investigate more fully the natural ageing of temper-rolled pure iron up to one month of ageing, but we had not sufficient material available to do so.

In reply to Dr. Hundy, the pure iron *BS*, which we used in our earlier paper is of the same batch of pure iron as the *AHP6*, but it was not the same sample. Without going into it more fully, I would not wish to comment any further on the differences in the ductility. Dr. Hundy showed a graph of the removal of carbon and nitrogen in moist hydrogen. We have done some more experiments with moist hydrogen, using an O.H. steel, and we could remove the yield point and strain age completely in about 16 h, compared with 5 days.

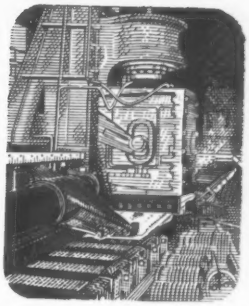
Dr. **B. Jones:** I should like to pay a tribute to the work carried out by B.I.S.R.A. and also to the fundamental work which has been carried out at the British Universities: first of all at the University College of Swansea by Dr. C. A. Edwards, and then by Dr. Polakowski and Professor Cottrell at the University of Birmingham, and Dr. Bilby at the University of Sheffield. Without all this fundamental work at the universities, all the work that we do on strain ageing today could not be explained.

REFERENCES

1. W. R. Thomas and G. M. Leak: *J. Iron Steel Inst.*, 1955, vol. 180, pp. 155–161.
2. B. Jones and R. A. Owen-Barnett: *Ibid.*, 1955, vol. 180, pp. 20–21.
3. A. H. Cottrell and B. A. Bilby: *Proc. Phys. Soc.*, 1949, vol. 62, ser. *A*, pp. 49–62.
4. Von W. Dahl and K. Lücke: *Arch. Eisenhüttenwesen*, 1954, vol. 25, pp. 241–250.
5. S. Harper: *Phys. Rev.*, 1951, vol. 83, pp. 709–712.
6. B. A. Bilby: *Phys. Soc. Japan*, 1955, vol. 10, pp. 673–679.
7. H. L. Wain and A. H. Cottrell: *Proc. Phys. Soc.*, 1950, vol. 63, ser. *B*, pp. 339–345.
8. D. Turnbull: "*Report of Conference on Defects in Crystalline Solids*," pp. 203–211: 1955, London, The Physical Society.
9. B. B. Hundy: *Metallurgia*, 1956, vol. 53, pp. 203–211.

IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



Report of the 29th Engineers Group Meeting

The Twenty-Ninth Meeting of the Iron and Steel Engineers Group of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 14th December, 1955. Mr. A. Taylor was in the Chair at the beginning of the Meeting, and his place was later taken by Mr. W. M. Larke, Chairman of the Group.

At the Morning Session a Paper entitled "The Roller-Straightening of Sections and Rails," by Mr. W. A. J. Dinwoodie (Lamberton and Co., Ltd.), was presented and discussed: a report of the discussion appeared in the August, 1956, issue of the *Journal* (vol. 183, pp. 423–432).

The Afternoon Session was devoted to two papers on "Flying Shears for Bars and Billets," by Mr. R. Stewartson and Mr. S. R. Phelps (Guest Keen and Nettlefolds (South Wales) Ltd.), respectively; the discussion on the papers appears below.

DISCUSSION ON MECHANICAL DESIGN AND ELECTRICAL REQUIREMENTS OF FLYING SHEARS

This discussion was based on the following papers (the dates of publication in the *Journal* in parentheses):

"Mechanical Design of Flying Shears," by *R. Stewartson* (1955, vol. 181, Nov., pp. 232-247).

"Electrical Requirements for Flying Shears," by *S. R. Phelps* (1955, vol. 181, Nov., pp. 247–262).

Mr. **E. R. Henschker** (Loewy Engineering Co., Ltd.): One problem with billet shears is to obtain a clean cut, without fins and bent ends, which are so troublesome in the re-heating furnace and on entry into the next mill.

With this in view, we have applied the action of an up-cut shear with the top blade moving in a straight horizontal line during the cut, skimming over the top of the billet whilst the lower blade performs the cut from underneath and pushes the cut-off piece only slightly upwards. Figure *A* illustrates the layout. This means that the billet delivered by the mill and held by one or two pairs of pinch rolls is neither bent down nor bent upwards by the action of the shear and the measuring roller which is situated about 5 ft from the shear is not disturbed through vibration and gauges the cutting length more accurately.

Reversion to the flag switch in the run-out table as used with steam shears, or the use of an electric eye adjustably mounted in the run-out table has been suggested, but apart from the fact that such equipment would be prone to damage, I doubt if it would give better results than the electronic counter driven by the aforementioned measuring roller, with which we obtained a tolerance of $\pm$ 1½ in. on 30-ft cutting lengths.

With any electric shear there is a time lag from the signal to the actual cut, during which interval any variation in the delivery speed will affect the cutting length. There are fluctuations in the mill-motor speed and in the forward slip of the stock in the last pair of rolls as soon as the tail end has left the stand before the last; this explains why it is mostly the first and last pieces which differ in length whilst the intermediate pieces are uniform.

To improve the accuracy still further, one should reduce the acceleration time by reducing the WR^2 to the utmost, reduce friction by incorporating roller bearings and, in addition, keep the delivery speed of the mill rigidly constant.

The electric drive is so much more rigid than the earlier steam drive and for this reason, we have arranged a flexible link between crankshaft and oscillating lever fitted with a powerful spring, which can compensate for small differences in the basic speeds of the shear motor and the mill motor, as well as counteracting the sinus effect of the crank; by this device, wear and tear is greatly reduced; the shear of which I am speaking had only two delays during the last six months, one lasting 40 min and the other 45 min.

A further aim of our design is to facilitate the disposal of the crop ends, which are directed downwards into bins. The length of the front end can be controlled; the tail end, however, can be any length. If the tail end is short, it will fall down into the bin; if it is long, it will be carried through the shear to the delivery table, from where it has to be removed.

With regard to shears for thin stock, I was interested to learn that in one design an air-operated clutch is used instead of a magnetic clutch. I would like to know the delay from the signal to the actual cut in this case.

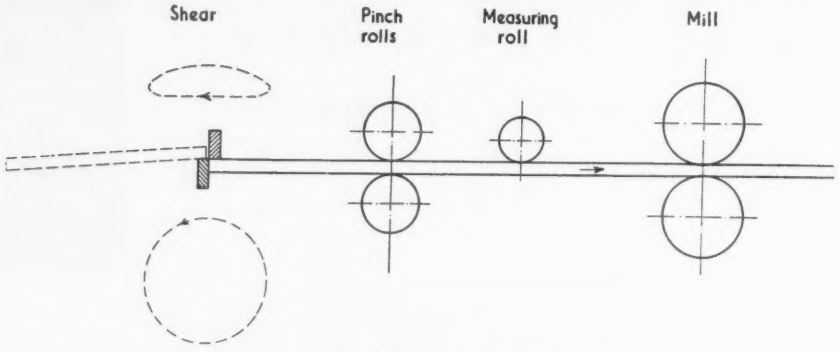


Fig. A—Layout of action of up-cut shear

From the maintenance point of view, the start and stop shear without clutch is very attractive, but this shear requires for the same programme and speed, nearly six times the installed horsepower, and the acceleration time is nearly twice that of the clutch-operated shear.

Mr. **P. E. Peck** (British Thomson-Houston Co., Ltd.): Mr. Phelps described the electronic control of the shear and twist pipe on a disc shear. This has been developed in such a way that instead of the shear pipe starting in the down position and, after a delay as the nose of the piece comes through, rising to take the piece between the discs of the shear, it starts in the up position which is its normal position, and on the approach of a piece, drops to the down position and again comes up to perform the cut. The advantage is that the back end of the piece runs clear of the top of the rotating knives instead of dragging against them. Furthermore, should there be any unexpected failure in the photo-electric timing equipment, the natural position for the pipe to take up is the straight-through position, with the reasonable chance that the piece will enter and be rolled. Otherwise it is diverted straight down into the scrap pit as a complete length.

A further development is the control of the shear pipe to a third position where the stock can be diverted through a spoil pipe (or better a trough) in the event of a cobble further down the mill. With the type of shear which Mr. Stewartson described the remaining stock can be cut into lengths and sent down into the bin for scrap.

I should be interested to know Mr. Phelps' technique for checking the condition of valves and whether after a certain period he deliberately replaces all electronic tubes irrespective of their condition.

The visit to Consett impressed upon me the effect of the billet shear on the summation-load metering for the entire power plant, which could be seen to be fluctuating greatly when the shear made a succession of cuts on each billet.

Has the provision of a flywheel M.G. set been considered so as to avoid the large load swings as the shear accelerates and retards to make each cut ?

Mr. **M. Rathbone** (J. Lysaght's Scunthorpe Works Ltd.): My remarks are based on experience with the Morgan continuous-running flying shear.

Group 1*a* in Table I of Mr. Stewartson's paper covers the duty of this shear, but the accuracy of $\pm$ 2 in. in 30 ft quoted in the paper is easily attained at our installation. The production department guarantees an accuracy of $\pm$ 1½ in. and normally expects $\pm$ 1 in. on 30-ft lengths. This degree of precision is no less attributable to the electric flying shear than to the painstaking investigations by our mill electrical engineer, Mr. Culpin, whose efforts led to certain design alterations which produced accuracy of performance not envisaged by the manufacturers.

As Mr. Phelps points out, the Lysaght shear is self-timing once the cycle has been initiated. In practice, the inaccuracies due to variations in mechanical stiffness are not significant and are of a secular nature. Despite the apparent disadvantages of the shear control being of the open loop type and of no form of measuring system being utilized, the operation is generally perfectly satisfactory. The variations in lengths of cut that do occur are mainly associated with the operation of the 6-stand mill that precedes the shear. The mill is driven by a single motor, and the relative speeds of the various stands are thus fixed. Incorrect drafting of the mill will mean that bar speed and mill speed do not correspond, and the shear will cut progressively longer lengths as the mill empties.

In the original installation, measuring rolls were incorporated between the last mill stand and the shear to give a voltage indication of bar speed. These were later removed, partly because they were easily damaged, and, more important, because they would not indicate the true speed unless a correction was applied for the size of billet. Since the mill rolls many different sizes during the course of a week, this method of deriving the true delivery speed proved impracticable. The ideal solution would seem to be some device which would indicate delivery speed without involving physical contact with the billet. If this could be done, a closed loop system could be used with advantage.

Electronic control gear is not an essential for this type of billet shear. Once the starting sequence has been initiated on the Lysaght shear, the entire cycle is controlled by one cam-operated limit switch, and the complication of electronic control gear would seem to offer neither technical nor financial advantage.

I consider that the major problem in the introduction of electronic gear is not in relation to the gear itself but in the provision of suitable shift maintenance personnel, and I think that this is a valid objection unless a very clear advantage can be shown over the conventional contactor and rotating amplifier, with which the average electrician is already familiar. There are many applications for which electronic gear is eminently suitable, and in these cases I would submit that it is better to train steelworks electricians for electronic maintenance than to introduce electronic specialists into steelworks.

Using the electric shear, our loss of time attributable to electrical faults has been only 110 minutes in five years of operation representing 10 million cuts; it is

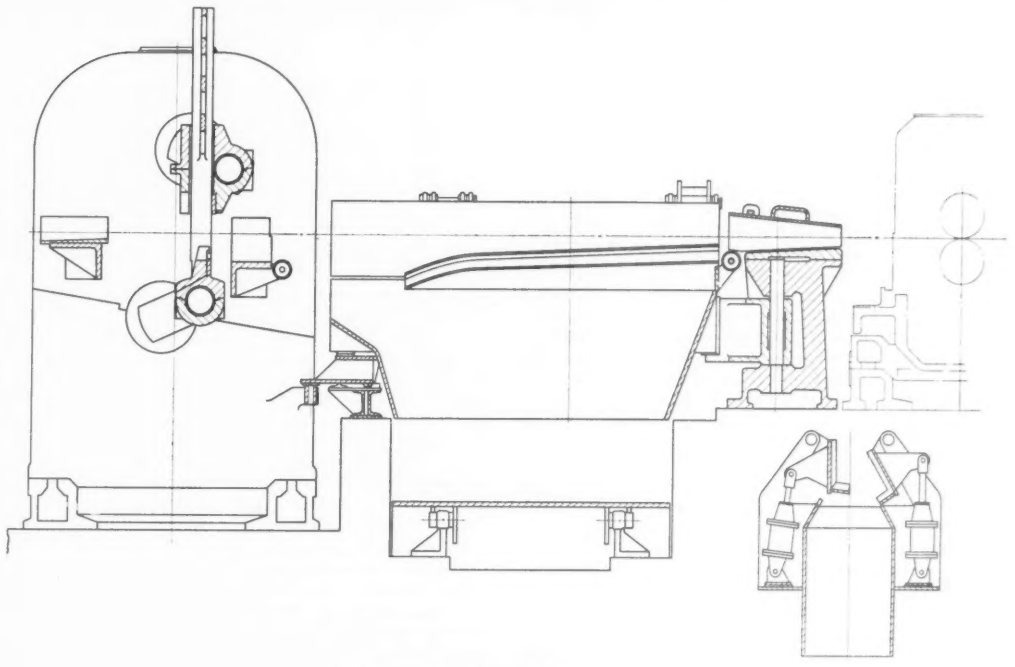


Fig. B—Crop collecting chute

also required to change length on an average eight times a shift and has on occasion changed 20 times in one shift. The change in length is easily effected in the normal free time between ingots, and, with experienced operators, there is negligible loss of steel in ' trimming ' the shear to cut the required length.

I consider that a clear case can be made for an electric flying shear for billet cutting on both economic and technical grounds.

Mr. **F. Taylor** (Buckley and Taylor, Ltd.): Adjuncts of the flying shear which perhaps lay outside the scope of Mr. Stewartson's paper, but are important in shear operation are the guide arrangements on the ingoing side and outgoing side of the shear. These are particularly important on crop shears, since arrangements must be made to dispose of, and collect the crop ends. The shear illustrated in Fig. 23 on Mr. Stewartson's paper was followed by the crop-end collecting chute shown in Fig. *B*; this consists of a trough split on the horizontal centre-line whose floor starts far enough away from the shear to allow the crop ends to pass underneath, but which picks up the oncoming bar guiding it to the entry guides of the following stand. On entry to this stand, air cylinders actuated by a load relay open the guide trough and allow the loop to form between the shear and the next stand. As the tail end of the bar leaves the mill the trough is closed ready to receive the next bar from the shear.

The crop end passes under the trough and on falling on to the butterfly deflecting plate is diverted to one of two changing boxes placed in pits on each side of the mill pass-line. As this particular shear is capable of lining up with any pass in the roll of the preceding stand the guide trough is arranged to move with the shear at its entry end whilst pivoting about its delivery end thus always delivering to the fixed pass-line through the finishing mill.

On cobble cutting the shear runs continuously at a high speed regardless of bar speed in order to keep lengths cut to a minimum. The trough controls are interlocked to keep the trough open whilst the shear is cobble cutting and the pieces are collected with the crop ends in the charging boxes.

In passing I would like to say that the design of the aforementioned shear has proved very satisfactory in practice; maintenance in over two years of operation has been negligible apart from attention to the blades every six weeks approximately. This design was developed primarily for cropping duties in bar mills, but the principle has been considered for other duties. Whilst substantial modifications would be necessary to allow its use for multi-strand cropping in a rod mill a very similar shear could be designed for use at the delivery end of a billet mill.

Mr. **H. Williams** (Metropolitan-Vickers Electrical Co., Ltd.): I should like to speak about flying billet shears, a relatively new problem to the electrical engineer.

On the stop-start shear we know the position of the blades at the start and all that is required is for us to accelerate the shear, decelerate it, and bring the blades back to the same position. At the same time we have to measure the length of stock which has passed through the mill. That can be done by means of an electronic counting unit or by photo-electric cell equipment. The photo-electric cell equipment is a later development than the electronic equipment and its use could dispense with electronic equipment.

The continuous-running or Morgan type shear presents a far more complex problem to the electrical engineer as the blade position and measurement of the stock have to be synchronized.

The stop-start shear has only one limiting feature and that is the minimum length the shear can cut. Both Mr. Stewartson and Mr. Phelps have mentioned

that the stop-start shear has to over-run. The two primary features on a drive of this nature are time and distance. The shear has to be accelerated in the shortest possible time and the distance travelled by the blades during this time must also be less than one revolution. If over-run is to be avoided, then it is necessary to accelerate in less than half a revolution.

The time to accelerate the shear is an electrical problem and up to date the best times are 0·4–0·5 s. The distance the blades travel is more of a problem for the shear designer, who has to arrange the relationship between the shear r.p.m. and blade peripheral speed.

Whilst the minimum length which any individual stop-start shear can cut may be reduced by arranging for no over-run, stop-start shears have a definite minimum cutting length, i.e. the distance travelled by the stock during acceleration and deceleration periods. Thus if billet mill speeds continue to increase, we may find that the stop-start shear has a limited application.

It may possibly be because of this limitation that the Morgan type shears have been developed. On this shear, cuts take place within one revolution, a different cut length being obtained by varying the speed of the blades during the non-cutting period. This feature helps considerably in reducing the minimum cut length possible, but it also introduces a new and very serious problem for the electrical engineer, namely that of relating the creep speed of the shear to length of stock passed through the shear and to the blade position. In the case of the Morgan type shear, the blade position depends on the idling speed and this speed must therefore be regulated to keep pace with any changes which may take place in the mill. It must be ensured that the shear blades are in the correct position to commence acceleration, and when they reach top speed to cut the material to the correct length. I would like the views of the authors on whether the problem is best tackled electrically or mechanically in view of the application they have described of a pneumatic clutch.

Mr. **H. R. Fernbach** (Loewy Engineering Co. Ltd.): The continuous-running shear with the slowing-down features presents some very interesting problems from a control point of view. The advantages compared with the start-stop shear are, however, rather problematical. As was pointed out by Mr. Phelps the main requirement of a flying shear is accurate length of cut. By the nature of the slowing-down shear certain inaccuracies are apt to occur unless, as already mentioned during the discussion, the shear is synchronized with the rolled product.

There are certain relationships which determine the inaccuracies due to difference between the material speed and the shear speed. Taking for example the diagram shown in Fig. 8 in Mr. Phelps' paper, and assuming a 12-ft cut length, it can be shown that an inaccuracy in speed of about 3% would cause an inaccuracy of roughly 2 in. in the cut length. This discrepancy in length is due to one factor only, to which must be added others which are common to both types of shears, and exceeds the total inaccuracies experienced on the start-stop shear. This on first consideration seems illogical but can be quite simply proved and understood by graphical example. The maximum velocity-duration, when this maximum velocity pertains, and time of each cutting cycle, are the same for both types of shears. Referring to Fig. *C* the full line represents the continuous-running shear and the dotted line the start-stop shear. The total path made by the start-stop shear during one cycle is the lightly shaded area and of the continuously-running shear the heavily shaded area. As the area equals the integral of velocity multiplied by time from zero to the end of the cycle it

Fig. C—Speed/time characteristics of continuous-running and stop-start shear

will represent the distance travelled by the shear. As both shears travel the same distance for one cycle the two areas must be equal; consequently the slope of the continuous-running area must be steeper than the slope of the area representing the start-stop shear. As the slope represents the acceleration it is apparent that acceleration for the start-stop shear is smaller. In view of this it may be necessary to install larger motors for continuous shears fulfilling the same duty cycle.

I would seriously suggest that the motor manufacturers should view the possibility of using rectifiers or invertors operated by grid control on flying shears. The obvious advantage is greater acceleration due to the rapid voltage build up and ease of acceleration and deceleration control; this may be offset by the heavy current peaks and the reactive loading on the supply, but most installations could easily absorb such extra loads; as even blooming and slabbing mills can now be operated by rectifiers, this aspect should not cause any particular difficulties.

A special feature of a disc shear recently installed in a continuous wire-rod mill in France is that the timers which are triggered by the photo-electric cells are designed to have an inverse time/speed characteristic and will therefore cut correct lengths independent of the rolling speed.

Before electronic equipment can come into more general use in rolling mill installations, manufacturers will have to increase valve life-expectations considerably.

Mr. **F. Starkey** (Brightside Foundry and Engineering Co.): Mr. Stewartson discussed shears of both the start-stop type and the continuous-running type in which the blades are brought into action by a clutch.

The outstanding merit of the start-stop shear is that its mechanical design is simple, robust, and cheap, leading to a negligible amount of downtime through mechanical troubles. There are no mechanical adjustments to be made whilst in operation, and no mechanical factors present causing variation in cutting behaviour.

However, for certain conditions, motors must be used which are large in relation to the energy used in the cut, and a generator must be used to provide the requisite variation in applied voltage for changing bar speeds. The most arduous duty of the motors is to accelerate to the correct cutting speed, which becomes critical at speeds in the region of 2000 ft/min, particularly if a heavy machine is required to cut large sections. When speeds are not so high, for example when nose cropping after a roughing mill train, or where smaller sections allow a lighter machine to be employed, the acceleration torque demanded can be met quite easily.

The first cost of the clutch-drive shear, including the electrical equipment may be somewhat less than that of the start-stop shear for the same duty, but the mechanical complications introduced by the clutch

and flywheel, and in some cases the blade resetting mechanism, must inevitably tend to increase maintenance time.

The use of an air clutch to connect the shear knives to the flywheel, and an air brake to arrest them after the cut, appeals on the grounds of simplicity but for the high finishing speeds of modern bar mills, these operations must be executed very quickly, and difficulty may be encountered in moving the quantities of air in the time available.

This leads naturally to the use of the electro-magnetic clutch drive. It is interesting to note that a start-stop machine of equal capacity to that described in the paper, would require two 35-h.p. motors at 575 rev/min, comparing with the 30/60-h.p. motor at 450–1150 rev/min quoted for the clutch-driven machine, and it would appear that a generator has been employed in this case also.

As an illustration of the difficulties of shear control at high speeds, it was found during the design stage of shear, illustrated in Fig. 20, that the normal cam-type limit switch could not accurately control the sequence of operations.

A special limit switch was designed using photo-electric cells having negligible time lags. A slotted drum is rotated by the shear crank giving a time indication of the angular position of the crank. A lamp mounted internally and free of the rotating drum forms the light source. Photo cells are mounted outside the drum, each one being focused on the line of travel of a particular slot, and receive an impulse when the light, slot, and cell are co-linear, accurately controlling the cycle of acceleration, cut, deceleration, and reset.

CORRESPONDENCE

Mr. **R. S. Gosling** (Llanelly Steel Company (1907), Ltd.) wrote: The authors suggest that the apparently primitive method of initiation and measuring that has been used successfully with a steam shear is all that is required, and Mr. Rathbone agreed. If this is so we should encourage production departments to specify no greater accuracy than their customers demand. It is not merely the initial cost of precision measuring components, but the additional possibilities of breakdown. As the authors emphasize, unnecessary refinements should be avoided; this point also applies to unnecessarily short lengths. With regard to the initiating device itself, I suggest that we do not dismiss the simple mechanical flag switch too arbitrarily; it is true that it has proved unsatisfactory with high stock-speeds and light sections, but for billets and slabs at about 400 ft/min, it can be adequately reliable. Routine week-end checking is quick and simple, and a fault in operation can be diagnosed immediately. The same cannot be said for P.E. relays, although they are obviously essential in a number of applications. I take it that the sensitivity of the lead-sulphide cell to ambient temperature is no disadvantage in this application, presumably owing to water cooling. I have had no operating experience of load relays, and would be glad to know why they are little used at the moment.

The authors mention the value of recording instruments, and I fully agree, but I do not think recorders should take the place of indicating meters, which may be miniature instruments grouped together. A knowledge of their general behaviour during the cycle, and the ability to check static values at a glance is very valuable, and in fact, may enable one to know where best to connect the recorders. I would be very pleased if someone would produce an industrial recorder that does not require ink.

I would be reluctant to accept that the use of electronics, in their present forms, is inevitable. It is necessary in this technique to get a large amount of circuitry into a small space, and well-known communication experience is available to enable this to be done, but I fully agree with the authors' suggestion that a design practice fulfilling more nearly traditional steelworks requirements should be aimed at. The necessity for complete stand-by equipment, for routine check or replacement of vital components such as valves, and for a discussion on how to train craftsmen to be experts in two different fields, points to a basic difficulty which we trust our manufacturers will solve. I agree that the average valve life exceeds 1000 h, but I have found most failures caused by inter-electrode faults and should be interested to know the average life of valves withdrawn from service due solely to emission decay.

I have no figures for the maintenance costs of an electric shear (in any case I do not think the amount over the first year or so would be a reliable index of the costs throughout its working life), but I find the power cost of a stop-start shear to be about double the figure quoted by the authors; and would like to know what is included in it.

The shearing load (Fig. 1 in Mr. Stewartson's paper) is shown to move from curve (*a*) to curve (*b*) with 10% clearance. As the authors stated, this is a condition which is not likely to persist long in practice; but is it the case that with hot mild steel substituted for cold lead, an approach to curve (*b*) may apply with much less clearance? Flying shear behaviour seems to suggest this.

It is mentioned that pinch-rolls between the last mill-stand and the shear will help to eliminate twist in a billet. I do not think they can be very effective in this, but their value is in maintaining a constant stock speed after the back-end is out of the last working stand, and the front end is being pulled by run-out rolls. Variation in stock speed under these conditions will not only affect the lengths cut (even if the measuring is in principle independent of this effect) but will also produce inferior cuts and greater shear loads. The relation between stock and blade speeds appears rather more critical than the authors suggest for optimum cutting.

I do not think the peak demands on the power system should vary much between stop-start and continuous-run types of shear. A continuous-run shear idling at $\frac{1}{2}$ cutting speed has to supply $\frac{3}{4}$ of its final K.E. in 80° of mechanical rotation (Fig. 8 in Mr. Phelps' paper). A stop-start shear has to supply its whole K.E., but has 200° or more in which to do so.

Mr. **L. Hargreaves** (Whitehead Iron and Steel Co., Ltd.) wrote: With the Morgan steam flying shear which we use for cropping the front end of the bar section, we find definite advantages after conversion to compressed air. After a mill delay, the shears are immediately ready for operation—many cobbles have resulted from a waterlogged shears cylinder when using steam; compressed air is also easy to dissipate from cylinder on exhausting. Flexible steam pipes are never satisfactory; air hose is more simple and cheaper to maintain. Incidentally, our blade bill has been halved since using Stellite-tipped blades, which are made up in our maintenance shop.

In 1928 and 1931, we made two rotary bar shears. Both these shears are at the head of 250-ft double-sided cooling beds. One is used for cutting $\frac{1}{4}$–$\frac{1}{2}$ in. rounds and small flats at speeds of 2000 ft/min and below, and the second cuts $\frac{1}{2}$–$1\frac{1}{4}$ in. rounds, flats, and skelp at speeds of 1500 ft/min and below.

These shears were constructed with two drums

geared together and rotating in a pair of housings; blades set in the middle of each drum meet at every revolution. Thus free pathway exists down either side of the blades; the shears are continuously rotating and are driven by a 25-h.p. motor which is adjusted to match the speed of the bar, plus trimming. Taken from the same drive is a simple clutch that moves the feed trough through the blade path from one side to the other at every actuation of a control lever, and is so arranged that the trough can only pass through the centre line of the blades when they meet to cut; such a shear can only be used for a double-sided cooling bed or a pair of rod reels where you have two distinct pathways for the bar.

We have found with experience that the shears are over-powered and a 10-h.p. drive would have been ample. The complete set-up can be manufactured by a steelworks maintenance shop at a cost less than the amount paid for one of the 100-h.p. d.c. motors required on shears mentioned in the paper. Our shears have been in continuous operation for 25 years; very little maintenance has been necessary.

In 1954, we decided to make the shears and bed on the larger mill entirely automatic. This was carried out successfully by fitting three miniature air cylinders to the racking-engine steam valves and shears clutch, and remotely controlling the cylinders with solenoid operated valves. Having the controls centralized, we fitted a photo-electric cell in the trough leading to the shears, with suitable adjustable timing relays to the air valves and a main over-riding timer to control the regularity of operations. By adjusting a dial at the head of the bed, we can thus cut a bar into any number of equal lengths and deliver the bars in an even line to any position on the bed.

We have since turned to the faster mill and found, on experimenting, that the photo-cell was not 100% reliable in picking up the edge of $\frac{1}{2}$ in. $\times$ $\frac{1}{2}$ in. bar. Neither could we relay the load on and off the mill motor of the last stand accurately.

We have now insulated the delivery pipe to the shears, and connected to a low voltage supply. The oncoming bar completes the circuit and tests have shown that we shall now be successful. We are preparing now to complete the work, which should be in operation in a few weeks.

AUTHORS' REPLY

Mr. **R. Stewartson:** The present position would appear to be that for billet shears at moderate stock speeds, a stop-start drive is adequate in conjunction with either a rotary or oscillatory linkage; an advantage of the latter, particularly the type of Fig. 2c, is explained by Mr. Henschker to lie in the up-cut action which can be obtained. For higher speeds, the stop-start cycle would demand very rapid acceleration and retardation; for example at 800 ft/min, 30-ft lengths require a cut every 2·4 s, and 20-ft lengths every $1\frac{1}{2}$ s. This, coupled with the overshoot associated with a stop-start drive and illustrated in Fig. 24, presents a very difficult problem.

The curve in Fig. *C* should be modified for overshoot in the case of the stop-start shear, to include negative speed beyond the point *B* during re-setting. Since this type covers something over 600° in its forward motion, the area corresponding to the 360° cycle of a continuous-running shear would be much less than that shown lightly shaded. This adds additional weight to Mr. Fernbach's point about the severe acceleration requirements for a continuous-running shear; it is not justified for moderate speeds.

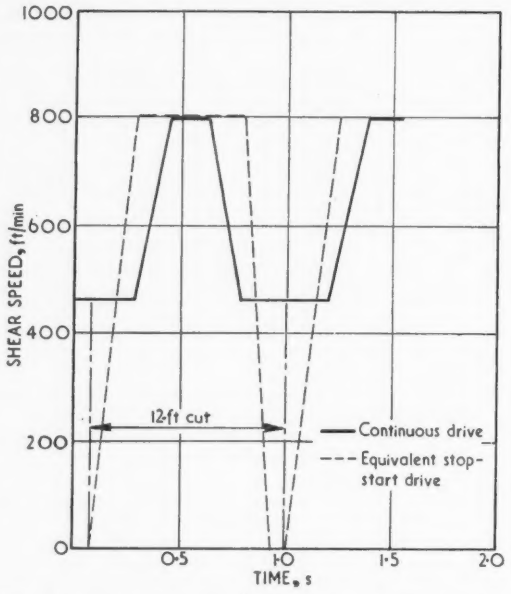


Fig. D—Comparison of start-stop and continuous-running drives for short lengths at high speeds

It should be pointed out, however, that at high billet speeds and for short lengths, the picture changes completely, since under such conditions the cycle time *OB* is lengthened, whereas *OC* representing the billet length in inverse proportion to the speed, decreases. In other words *B* and *C* approach and eventually overlap one another making necessary the elimination of overshoot and finally forcing a continuous-running situation on the designer, since to perform a full revolution in the time available, a stop-start drive would need to run at maximum speed for a major part of the cycle, as shown dotted in Fig. *D*, and the acceleration requirements become more severe than for the continuous-running drive. As Mr. H. Williams points out, increased billet mill speeds will show a limit to the application of a stop-start drive. The accuracy attainable with a continuous-running drive is exemplified by Mr. Rathbone's figures; they compare well with other types and reflect credit on all concerned.

Without full appreciation of local conditions, it is difficult to see why Mr. Gosling's stop-start shear should be more expensive in power cost than indicated in Table III of the paper. The number of cuts per ton of steel would probably be a major factor and some additional power may also be consumed in over-run and re-setting. Mr. Gosling stresses the importance of pinch rolls to hold stock speed constant as it leaves the preceding stands, and to this must be added their value in holding the free billet on the diagonal during the last cut. In answer to his comments on Fig. 1, one can only guess at the behaviour of hot steel compared with lead and indeed further work with lead using clearances between zero and 10% would be interesting in relation to the shape of curve 1*b*.

Mr. Taylor states that his shear runs continuously faster than the bar speed, when cobble cutting. This is permissible since in this case the possibility of stretching the stock or forming knuckles on the back ends is of no account, but one would expect that with heavy material, substantial side loads on the blades

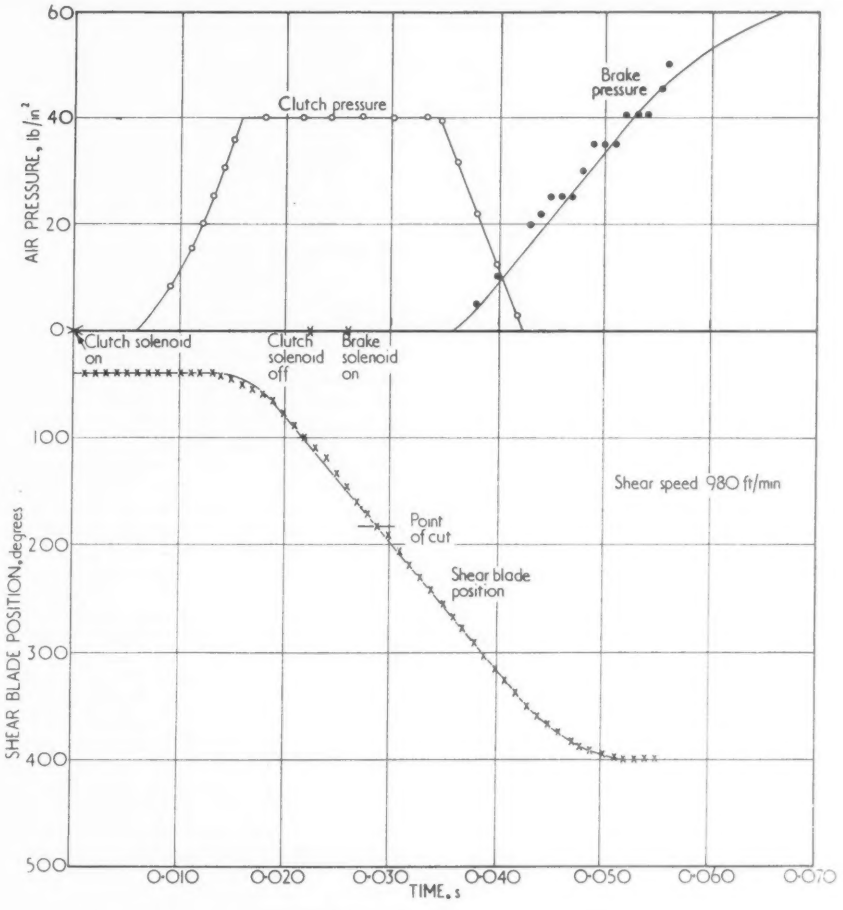


Fig. E—Clutch and brake pressure variation in pneumatic clutch drive

and slides might arise if the speed difference between the shear and the stock is excessive.

The pneumatic clutch design has so far been in operation for just over six months, each shear making something like 400,000 cuts without measurable clutch wear. Figure *E* will perhaps answer the questions of Henschker, Williams, and Starkey. The curves were obtained by high-speed cine photography during trials at 980 ft/min blade speed. Acceleration to running speed takes only 25° of revolution and about 0·005 s, although the delay between energizing the clutch valve solenoid and commencement of acceleration is about 0·013 s. No complicated re-setting mechanism is required and the two valves—clutch and brake—are simply controlled by limit switches. As for moving the quantities of air involved, the curves show that this is rapid, whilst the commencement of acceleration and retardation, coinciding with clutch and brake pressures of about 20 lb/in², indicates that the effective range of each is between 20 and 40 lb/in². The curves suggest that the clutch drive is applicable to much heavier rotating masses at slower speeds (billet mill duty) or equally well to increased blade crank radius for higher stock speeds (bar mill duty).

Turning to shears for thin stock, Mr. Peck describes recent improvement to disc shears in crop and cobble applications. The provision of a third position of the shear pipe to direct cobbles to one side has a useful application in mills of suitable layout, but if the system involves piping of any length, the possibility of short cobbles blocking the pipe may more than outweigh the advantages.

The advantages in converting a small steam shear to compressed air operation are well amplified by Mr. Hargreaves. The rotary shear he describes is of the type* described on page 246 in my paper which indeed provides a simple and reliable method of overcoming the difficulties in shearing at 2000 ft/min for cooling beds. It is, however, limited in accuracy, the tolerance being equal to the shear blade circumference, so that the type is applicable only to bar mill cooling beds and even there present trends are for accurate dividing to minimize shorts in cold shearing. Nevertheless, Mr. Hargreaves and his colleagues have to be congratulated on finding this simple and effective solution over 25 years ago when cooling bed shears were in their infancy.

*British Patent 305,023

Mr. **S. R. A. Phelps:** Mr. Henschker rightly states that with any electric shear there is a time lag from the signal to the actual cut; this time lag can be subdivided into two main components, namely, the time from the initial device giving the signal to the shear, and the time taken for the shear to respond having received the signal. It is probably true to say that electrically, the latter time period can be accurately determined and maintained. Different circumstances exist however, during the first timing period; immediately the initial device is operated, a preset time interval commences. During this interval, any variation in the delivery speed, slip of stock in the rolls, temperature, etc., will affect the cutting length. As stated, this will account for different lengths in the case of first and last pieces in a billet mill and for irregular lengths of front ends in the case of a rod mill. Also, as Mr. Rathbone points out, incorrect drafting of the mill will mean that bar speed and mill speed do not correspond and the shear will cut progressively longer lengths as the mill empties. A solution would appear to be a combination of two units, one for the initiation before the shear, and one for the cut length after the shear. In the case of a rod mill, the aim should be to place the initiating unit as close to the shear as possible, and in any case after the last rolling stand before the shear.

An application of a closed loop system is illustrated by the following simplified sketch (Fig. *F*). Basically, this is speed matching between the shear peripheral speed and the rod speed by means of a closed loop speed control. Rheostat 1 compensates for working roll diameter and to some extent forward slip, while rheostat 2 gives required excess peripheral speed of the shear above stock speed in order to facilitate the cut. An error is amplified in the electronics and fed on to the exciter push-pull fields; this exciter then feeds the generator speeds, which are in parallel. The two motors are in a normal series Ward-Leonard loop. An a.c. tacho connected by a set-up gear to the motor gives the requisite voltage proportional to the speed.

A limit switch, of the photo-electric cell unit type (as mentioned by Mr. Starkey) gives accurate control.

The question of the use of electronics is important, and particularly the type of person for maintaining these, and I fully concur with Mr. Rathbone's remarks. With reference to Mr. Peck's remarks, valves are tested for emission with a standard valve tester at periodic intervals. When a failure occurs, which can be traced

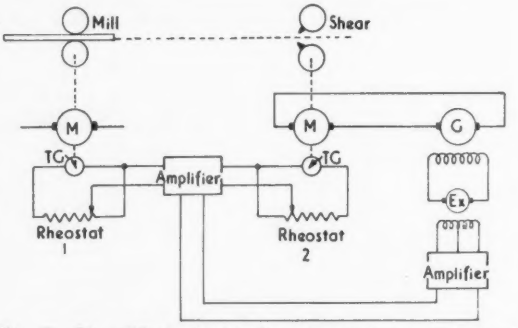


Fig. F—Simplified sketch for closed-loop control of shear

directly to a valve failure, the emission value is noted for future reference, and of course, in future, any other valve approaching this value would be removed. Generally speaking electronic tubes are only taken out of service when they are proved faulty.

Mr. Gosling mentions the photo-electric cell as compared with the mechanical flag switch, and Mr. Hargreave's comments on the reliability. With hot material, the lead-sulphide cell or infra-red photo-cell, seems to be more advantageous. The ambient temperature is no disadvantage but water cooling does assist, and where space is available the cells can be placed at least 4 ft away from the source, still maintaining a high degree of accuracy. Experience has shown in a rod mill that where a normal photo-electric cell has failed to operate on the starting shift, due to cold front ends, etc., an infra-red unit is unaffected by these conditions.

It would appear that load relays operating off load from the stand motor, suffer from the disadvantage of the large range of pick-up required, and of course in the case of a rod mill with more than one pass, it would be extremely difficult to detect each pass.

Regarding the supply for shears, a flywheel M.G. set as mentioned by Mr. Peck might prove advantageous with a continuous-running type of shear. However, with the stop-start type of shear and even to a lesser extent the continuous shear, the duty cycle would have to be compared with the build-up time required for the flywheel. Mr. Fernbach's suggestion regarding grid-controlled rectifiers certainly has the advantage with regards to the acceleration problem.

The Carbon Deposition Reaction over Iron Catalysts

By J. Taylor

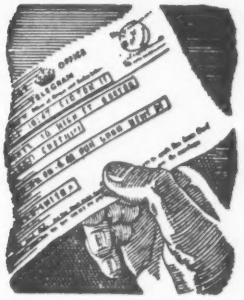
(*Continued from p.* 6)

References

1. W. Baukloh and E. Spretler: *Arch. Eisenhüttenwesen*, 1939, vol. 13, pp. 223–226.
2. U. Hofmann: *Ber. deut. chem. Ges.*, 1928, vol. 61, pp. 1180–1195.
3. H. Tutiya: *Sci. Papers, Inst. Phys. Chem., Tokyo*, 1929, vol. 10, No. 178, p. 69.
4. A. Juliard, R. Rayett, and A. Lude: *Trans. Faraday Soc.*, 1948, vol. 133, pp. 193–196.
5. R. S. Hilpert and R. Schacht: *Ber. deut. chem. Ges.*, 1937, vol. 70, pp. 1437–1446.
6. F. Olmer: *Rev. Mét.*, 1942, vol. 38, pp. 129–134.
7. W. Baukloh and G. Hieber: *Z. anorg. u. allgem. Chemie*, 1936, vol. 226, pp. 321–332.
8. W. Gluud, K. V. Otto, and H. Ritter: *Ber. deut. chem. Ges.*, 1929, vol. 62, pp. 2483–2485.
9. H. A. Bahr and V. Jessen: *Ibid.*, 1933, vol. 66, pp. 1238–1247.
10. U. Hofmann and E. Groll: *Z. anorg. u. allgem. Chemie*, 1933, vol. 191, pp. 414–428.
11. G. Hägg: *Zeitschrift für Kristallographie*, 1934, vol. 89, pp. 92–94.
12. K. H. Jack: *Proc. Roy. Soc.*, 1948, vol. 195, pp. 56–61.
13. B. Fleureau: *Compt. Reńd.*, 1953, vol. 237, pp. 330–332.
14. D. S. Laidler and J. Taylor: *J. Iron Steel Inst.*, 1950, vol. 165, pp. 23–38.
15. W. C. David and G. R. Rigby: *Trans. Brit. Ceram. Soc.*, 1954, vol. 53, pp. 511–523.
16. V. P. Kamzolkin and V. D. Livshits: *J. Chem. Ind. (USSR)*, 1937, vol. 14, pp. 244–249.
17. Y. Murata and J. Hara: *J. Chem. Soc. (Japan), Ind. Chem. Section*, 1950, vol. 53, pp. 338–340.
18. W. Baukloh and G. Henke: *Metallwirtschaft*, 1940, vol. 23, pp. 463–470.
19. F. Bertant: *Compt. Rend.*, 1950, vol. 230, pp. 213–215.
20. F. V. Wangenheim: *Brennstoff Chemie*, 1927, vol. 8, pp. 385–388.

N E W S

Announcements and News of Science and Industry



IRON AND STEEL INSTITUTE

Corrosion Meeting

By arrangement with the British Iron and Steel Research Association, The Iron and Steel Institute is organizing a Corrosion Meeting to be held at its offices, 4 Grosvenor Gardens, London, S.W.1, on Friday, 12th October, 1956, commencing at 10 A.M. and continuing all day. The Chair will be taken by Dr. H. H. Burton, C.B.E., President of the Institute, supported by Dr. J. Pearson, Assistant Director of the Association.

The following is the programme of papers with approximate timings, and the dates of publication in the Institute's *Journal*:

10.0–11.0 A.M.—"The Corrosion Resistance of Low-alloy Steels." By J. C. HUDSON and J. F. STANNERS. (*July*, 1955.)

11.0–12.0 noon.—"The Corrosion Resistance of Wrought Iron." By J. P. CHILTON and U. R. EVANS. (*October*, 1955.)

12.0 noon–12.15 P.M.—Interval.

12.15–1.15 P.M.—"Corrosion Resistance of Some Austenitic Cr–Ni Steels of 18/8/Ti Composition. The Effect of Variation in Chemical Composition and Thermal Treatments." By E. J. HEELEY and A. T LITTLE. (*March*, 1956.)

1.15–2.30 P.M.—Buffet Lunch in the Library.

2.30–3.30 P.M.—"Effects of Sulphate–Chloride Mixtures in Fuel-ash Corrosion of Steels and High-nickel Alloys." By H. T. SHIRLEY. (*February*, 1956.)

3.30–4.45 P.M.—"The Stress-corrosion Cracking of Austenitic Stainless Steels. Part I. Mechanism of the Process in Hot Magnesium-chloride Solutions." By T. P. HOAR and J. G. HINES. (*February*, 1956.) "Part II. Fully Softened, Strain-hardened, and Refrigerated Material." By J. G. HINES and T. P. HOAR. (*October*, 1956.)

This is an Open Meeting. Anyone interested in the subjects for discussion is welcome to attend and join in the proceedings, even though not a member of The Iron and Steel Institute. Non-members should write to the Secretary of the Institute, 4 Grosvenor Gardens, London, S.W.1, intimating their wish to be present.

At the conclusion of the Meeting a colour film entitled "Zinc Controls Corrosion," produced by the American Zinc Institute Inc., and kindly made available by the Zinc Development Association, London, will be shown.

NEWS OF MEMBERS

Mr. **W. Ash** has been appointed Chief Works Metallurgist at Steel, Peech and Tozer.

Mr. **L. J. Balasundaram** has been awarded the degree of Master of Metallurgy in the University of Sheffield.

Mr. **L. H. Cope** has resigned his appointment as Lecturer in Metallurgy at Corby Technical College to take up a post as a Senior Scientific Officer in the Research and Development Branch of the U.K. Atomic Energy Authority, Industrial Group Headquarters, Risley, Warrington.

Dr. **C. J. Dadswell** has been elected Vice-Chairman of the British Steel Founders Association.

Mr. **J. T. W. Dewar** has been appointed an additional Director of the English Steel Corporation Ltd.

Mr. **A. W. Durrant** has been transferred from the Drawing Office of the British Iron and Steel Research Association, Battersea, to the Fuel Section of the Physics Department.

Mr. **B. S. Ekelund** has left the Stora Kopparberg Corporation to take up the appointment of Head of the Metals Research Section of the Bjorksten Research Laboratories, Madison, Wisconsin, U.S.A.

Dr. **J. E. Garside,** formerly Head of the Department of Applied Chemistry of Northampton Polytechnic, London, has been appointed Principal of the Borough Polytechnic, London, S.E.1.

Mr. **T. H. Harley** has taken up the appointment of Assistant Sales Manager with the Vesuvius Crucible Company, Pittsburgh, Pennsylvania.

Mr. **R. J. Harris** has been awarded an Honours degree in Metallurgy at University College, Swansea.

Mr. **C. H. Hayter** has been appointed Works Manager (Services) at Steel, Peech and Tozer.

Mr. **H. W. G. Hignett** has been appointed Assistant Managing Director of Henry Wiggin and Co., Ltd.

Mr. **K. E. Jermy** has taken up an appointment as Technical Editor with the Research and Development Branch of the U.K. Atomic Energy Authority, Industrial Group, at Capenhurst Works, near Chester.

Mr. **Kehsin Kuo** has left Sweden to take up an appointment with the Institute of Metal Research, Academia Sinica, Shenyang, Mukden, China.

Mr. **G. M. Menzies** has been elected Chairman of the British Steel Founders Association.

Mr. **E. Oldfield,** formerly General Sales Manager, has been appointed Sales Director of The New Conveyor Co., Ltd., Birmingham.

Mr. **A. G. B. Owen** has joined the Executive Committee of the Welsh Economic Development Council.

Dr. **N. J. Petch,** Reader in Metallurgy at Leeds University, has been appointed Professor of Metallurgy and Head of the Department from 1st October, 1956.

Mr. **B. N. Prasad** has joined the Melting Shop Department of Skinningrove Iron Co., Ltd.

Mr. **A. G. E. Robiette** has been awarded the degree of Doctor of Science of the University of Wales.

Mr. **T. B. Smith** has been awarded the degree of Ph.D. in the Department of Physical Metallurgy at the University of Birmingham and has also taken up an appointment as a Physical Metallurgist in the Research Laboratory of the British Thomson-Houston Co., Ltd., Rugby.

Mr. **W. Udall** has been appointed to the Board of The Brightside Foundry and Engineering Co., Ltd.

Dr. **Howard K. Worner** has been re-elected as Federal President of the Australian Institute of Metals.

Obituary

Mr. **James Bussey** (*elected* 1938), of Sheffield, on 15th June, 1956.

Mr. **George Marlow Graham** (*elected* 1948), of Jørpeland, Norway, on 21st June, 1956, at the age of 65.

Mr. **Kenneth Menzies** (*elected* 1934), of London, on 6th June, 1956.

Mr. **James Montgomery** (*elected* 1942), of Motherwell, Lanarkshire, in April, 1956.

IRON AND STEEL ENGINEERS GROUP

By invitation of the Steel Company of Wales Ltd., the Thirty-first Meeting of the Iron and Steel Engineers Group will be held in South Wales on Thursday and Friday, 4th and 5th October, 1956. The programme of the Meeting is as follows:

Thursday, 4th October

9.30 A.M.–12.15 P.M. Technical Session at the Grand Pavilion, Porthcawl: presentation and discussion of a paper on "The Engineering Aspects of a Modern Basic Bessemer Plant," by Dr. C. HERRMANN (Demag AG, Duisburg).

1.45–4.45 P.M. Visit to Margam Works of the Steel Company of Wales Ltd.

Friday, 5th October

9.30 A.M.–12.15 P.M.—Technical Session at the Grand Pavilion, Porthcawl: presentation and discussion of a paper on "The Planned Change-over of a High-lift Slabbing to a Universal Mill," by Mr. C. E. H. MORRIS and Mr. R. N. DALE (Steel Company of Wales Ltd.).

1.45–4.45 P.M. Visits to Margam and Abbey Works.

Luncheon on both days and dinner on the Thursday are by invitation of the Steel Company of Wales Ltd.

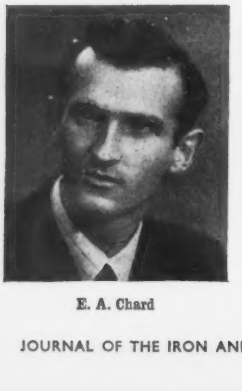
CONTRIBUTORS TO THE JOURNAL

E. A. Chard, B.Sc.(Eng.)—Technical Assistant with the Metallurgical Equipment Export Company.

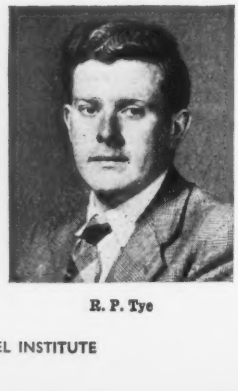
Mr. Chard graduated at University College, Southampton, in 1949 with the degree of B.Sc. in Mechanical Engineering, and took up a post as Junior Engineer in the Port Talbot office of the International Construction Company. From 1952 to 1955 he was a Scientific Officer in the Plant Engineering Division of the British Iron and Steel Research Association.

R. P. Tye—Assistant Experimental Officer, National Physical Laboratory.

Mr. Tye was educated at the Ledbury Grammar School in Herefordshire. He joined the Staff of the National Physical Laboratory in 1947 and is now an Assistant Experimental Officer working on the thermal and electrical conductivities of metals and alloys at high and low temperatures.



E. A. Chard



R. P. Tye

P. W. Willows, B.Sc.—Development Engineer with Kelvin and Hughes Ltd.

P. W. Willows

Mr. Willows was born in 1926 and was educated at Leyton County High School, London, and at the Battersea Polytechnic, from which he graduated in 1954. From 1945 to 1951 he was with the Powell Duffryn Research Laboratories Ltd., investigating high-temperature problems connected with carbon manufacturing processes, and from 1951 until recently with the British Iron and Steel Research Association working on the determination of the total heats of iron.

T. W. Johnson, B.Sc.—Senior Scientific Officer, Ironmaking Division, British Iron and Steel Research Association.

Mr. Johnson was born in 1925 and was educated at Grangefield Grammar School, Stockton-on-Tees. He spent two years with the Research Department of Imperial Chemical Industries Ltd. (Billingham Division) before joining H.M. Forces. In 1951 he gained a London University General Degree and a London University Special (Physics) Degree from Sunderland Technical College and joined the Health Physics Staff of the Atomic Energy Commission at Windscale Works. Mr. Johnson took up his appointment with B.I.S.R.A. in May, 1953.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

10th Junior Steelmaking Conference

This conference was held at the Hotel Majestic, Harrogate, on 20th and 21st June, under the Chairmanship of Mr. W. Geary, of the Appleby-Frodingham Steel Company. This, the first junior steelmaking conference to be held at Harrogate, was particularly well attended: 120 people were present, compared with an average of 80 in the past.

In the first session papers on casting-pit practice were presented by Mr. D. J. D. Unwin of the Park Gate Iron and Steel Co., Ltd., and Mr. W. C. Fletcher of Stewarts and Lloyds Ltd., Corby. In the second session Mr. J. Mitton of Round Oak Steel Works Ltd. spoke on O.H. furnace refractories, and Mr. R. Wilcock of Samuel Fox and Co., Ltd. read a paper on the comparative economics of electric and O.H. furnaces. As a supplement to Mr. Wilcock's paper Mr. J. Spooner, Chief Cost Accountant of the United Steel Companies, contributed an explanation of scrap and pig iron prices.

The formal sessions were followed by visits to three steelworks at Scunthorpe: the Appleby-Frodingham Steel Company, John Lysaght's Scunthorpe Works Ltd., and Richard Thomas and Baldwins Ltd.

Works Transport Conference

A conference on Works Transport was held under the auspices of the Plant Engineering Division of B.I.S.R.A. on 3rd and 4th July, in Sheffield, and was attended by almost 200 delegates. Papers were given on experiences in Britain, France, and Canada with Road Transport for the movement of bulk, semi-finished, and finished materials. On the second day a demonstration of over 50 vehicles used in steelworks was given at the 11-in. Bar Mill site of the Park Gate Iron and Steel Company. Equipment on show included fork lift trucks, mobile cranes, dumper trucks, mobile conveyors, special lorries, and many special-purpose machines, including the 'Gradall.'

9th Junior Blast-furnace Conference

The 9th Junior Blast-furnace Conference was held at Harrogate on 2nd and 3rd May, 1956, and was attended by 89 members. Mr. H. G. W. Debenham took the Chair and during the sessions the proceedings were under the guidance of two Vice-Chairmen, Mr. O. Franks and Mr. R. G. Roberts.

At the first session a paper by Mr. E. H. Baldwin was presented, which dealt with general aspects of blast-furnace operation, and described how the various factors affecting the performance of the furnace were assessed by the operator. The operation of a blast-furnace depended primarily on changing conditions such as the exact weight and constant chemical composition of the ore, coke quality, and ash content. Since the furnace operated continuously and there would be a time lag between observations and the effect of corrective action, the operator had to study the factors which influenced the steady working of the furnace. Measures to counteract fluctuations were described.

In the second part of the first session a paper was presented by Mr. A. Embleton describing typical American practice. Notable features seen during a visit to the U.S.A. were commented on, including the increasing use of high top pressure.

The second session was introduced by Mr. J. J. Evans with a paper which described blast-furnace plant and practice at the Shotton Works of John Summers and Sons Limited and gave a detailed survey of the special features connected with the construction of the plant, ore handling, and the operation of the furnaces.

In the third session Conference members split into four discussion groups and in the following session the elected chairman of each group presented a summary of the discussion to the whole Conference.

The Conference concluded with two papers presented by members of the Ironmaking Divisional Staff describing current aspects of research in the Division. Mr. E. W. Voice described the theory of sintering and its application to practice and Mr. J. M. Ridgion reviewed present and future methods of iron production. Each paper was followed by a general discussion, the main points of which were summarized by the Chairman in his closing statement to the Conference.

AFFILIATED LOCAL SOCIETIES

Staffordshire Iron and Steel Institute

The following Officers have been elected for the session 1956–57:

President	A. Biddulph, A.I.M.
Senior Vice-President	G. Parkin, F.R.I.C., F.I.M.
Junior Vice-President	W. H. B. Wesson
Trustees	P. Jump, M.I.MECH.E. H. E. Cookson, T.D. W. H. Lewis, M.I.MECH.E.
Hon. Secretary ..	H. J. E. Jones
Hon. Treasurer ..	G. E. Lunt

Members of Council

W. Angus, G. R. Bashforth, F.I.M., W. K. V. Gale, G. T. Hampton, F.I.M., A. Howard, W. M. Larke, B.A., M.I.MECH.E., K. G. Lewis, M.SC., M.SC.(TECH.), F.I.M., F.R.I.C., M.I.PROD.E., M. R. Liddiatt, A.I.M., Dr. E. Marks, J. Mitton, B. V. Peters, A. W. Shore, A.M.I.MECH.E., N. F. Truman, Dr. W. M. S. Walker, F. V. Wright, A.M.I.MECH.E., K. H. Wright, F.I.M.

Swansea and District Metallurgical Society

The following Officers and Council have been elected for the session 1956–57:

President	R. Walker
Vice-Presidents ..	J. S. Caswell, M.SC., M.I.MECH.E., A.M.I.C.E. H. A. Cooke
Hon. Secretaries ..	M. J. A. Thomas, B.SC. H. A. Cooke
Hon. Treasurer ..	L. A. S. Perrett, F.I.M.

Council

D. A. Bishop, A.I.M., S. S. Carlisle, M.SC., R. G. Davies, J. Hey, Dr. R. Higgins, O.B.E., F.I.M., W. R. Hitchings, D. W. Hopkins, M.SC., P. Mackay, R. J. Thomas, A.I.M., and R. L. Williams.

DIARY

1st–9th Sept.—VEREIN DEUTSCHER GIESSEREIFACHLEUTE—23rd International Foundry Congress and the International Foundry Trade Fair—Düsseldorf.

4th–11th Sept.—INTERNATIONAL GEOLOGICAL CONGRESS—Twentieth Session—National University, Mexico City.

5th–13th Sept.—INTERNATIONAL UNION OF MECHANICS—9th International Congress of Applied Mechanics—University of Brussels.

6th–7th Sept.—BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Open Days—Hoyle Street, Sheffield 3.

10th–14th Sept.—INSTITUTION OF MECHANICAL ENGINEERS (jointly with the American Society of Mechanical Engineers)—International Conference on Fatigue of Metals—Institution of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1, 10 A.M. each day.

10th–15th Sept.—THIRD INTERNATIONAL CONGRESS ON HIGH-SPEED PHOTOGRAPHY—Government Offices, Horseguards Avenue, London.

13th Sept.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Visit to Mobil Oil Co., Ltd. Refineries, Coryton, Essex—depart Wolverhampton, 7.50 A.M.

16th–18th Sept.—INSTITUTE OF WELDING—Conference on "*The Functions and Education of Welding Engineers*"—Ashorne Hill, near Leamington Spa.

20th–21st Sept.—DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH—Mechanical Engineering Research Laboratory—Open Days—East Kilbride, Glasgow.

20th–22nd Sept.—VEREIN EISENHÜTTE ÖSTERREICH—International Rolling-mill Conference—Montanistische Hochschule, Leoben, Austria.

24th–27th Sept.—UNIVERSITY OF SHEFFIELD, Department of Extramural Studies—Course on "*Air Pollution*"—Sheffield University.

24th–28th Sept.—NATIONAL INDUSTRIAL FUEL EFFICIENCY SERVICE—Third Annual Refresher Course for Works and Plant Engineers, "*Current Practice in Fuel Efficiency*"—Clarendon Laboratory, Oxford.

26th–28th Sept.—DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH—International Symposium on "*The Direction of Research Establishments*"—National Physical Laboratory, Teddington, Middlesex.

TRANSLATION SERVICE

(The previous announcement was made in the July, 1956, issue of the *Journal*, p. 319.)

TRANSLATION IN COURSE OF PREPARATION

(German). H. U. MEYER: "The Influence of Alloying Elements on the Surface Hardenability of Case-hardening Steels." (*Stahl u. Eisen*, 1956, vol. 76, 26th Jan., pp. 68–78).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

CONTENTS

	PAGE
Mineral Resources	80
Ores—Mining and Treatment	80
Fuel—Preparation, Properties, and Uses	81
Temperature Measurement and Control	82
Refractory Materials	83
Blast-Furnace Practice and Production of Pig Iron	84
Treatment and Use of Slags	85
Direct Processes	86
Production of Steel	86
Production of Ferro-Alloys	88
Foundry Practice	88
Heating Furnaces and Soaking Pits	93
Heat-Treatment and Heat-Treatment Furnaces	93
Forging, Stamping, Drawing, and Pressing	94
Rolling-Mill Practice	94
Machinery for Iron and Steel Plant	95
Lubricants and Lubrication	96
Welding and Flame-Cutting	96
Machining and Machinability	97
Cleaning and Pickling	97
Protective Coatings	98
Powder Metallurgy	99
Properties and Tests	100
Metallography	104
Corrosion	107
Analysis	109
Industrial Uses and Applications	111
Economics and Statistics	111
Miscellaneous	111
New Publications	112

MINERAL RESOURCES

Iron Ores: Some Considerations on Their Availability, Properties, and Usage. D. Joyce and B. Marsden. (*Canad. Min. Met. Bull.*, 1955, **48**, Nov., 727–732). The potential world resources of iron ore are discussed, particularly in relation to Canadian production. The required properties of iron ores are outlined and typical Canadian grades are given. Algoma Steel Corporation blast-furnace practice is described and the effect of beneficiation is mentioned.—T. E. D.

Iron Ore Supplies Will Outlast Us. (*Steel*, 1955, **137**, Nov. 7, 87–89). Present and future supplies of iron ore in U.S. are discussed. Estimates of future trends are given. Increasing tonnages will be imported and upgrading treatments will expand.—D. L. C. P.

Additions to the Study of the Lorraine Iron Ore Basin. II. The Algrange Region: Saint-Barbe, Angeuillers, Burbach. II (ctd.). The Landres Basin: Tucquegnieux and Anderny. L. Coche, D. Dastillon, M. Deudon, and P. Emery. (*IRSID*, 1955, Feb., 83 pp., May, 71 pp.). The black, brown, grey, red, and yellow beds are analysed and tested. (*ctd.*). Chemical analyses, mineralogical description and analyses, and the results of enrichment tests are reported for samples from the grey and red ore beds.—T. E. D.

The St. John Del Rey Mining Company, Limited, Minas Geraes, Brazil. A. F. Matheson. (*Canad. Min. Met. Bull.*, 1956, **49**, Jan., 37–43). The history, geology, and mineral resources of the 150 sq. miles of land owned by the company are described. About 25 sq. miles are underlain with itabirite carrying about 40% Fe. The chief manganese minerals are pyrolusite and psilomelane, some containing 48–60% Mn.

Manganese Exploration in the Philipsburg District, Granite County, Mont. J. S. McNabb. (*U.S. Bur. Mines Rep. Invest.* 5173, 1955, Dec.). A detailed report on the ore bodies of this district is presented.—B. G. B.

Investigation of Tombstone District Manganese Deposits, Cochise County, Ariz. A. B. Needham and W. R. Storms. (*U.S. Bur. Mines, Rep. Invest.* 5188, 1956, Feb.). Exploration work carried out in this district is described. Results indicate that no great tonnage could be expected from any individual deposit.—B. G. B.

An Expert Looks at Iron Ore Sources in 1984. (*Eng. Min. J.*, 1955, **156**, Dec., 86–89). An estimate is made of the ore requirements of the U.S.A. for all years up to 1984, based on an ingot capacity by then of 155 million (short) tons. Ore requirements will be 153 million (long) tons, and will be met by large increases in imports and in output of concentrates.

Transitions in Raw Materials for Iron Manufacturing after War in Japan. Y. Asada. (*Tetsu to Hagane*, 1955, **41**, July, 702–713). [In Japanese]. Annual figures for imports and domestic production of Fe ore, Mn ore, coal, and scrap are analysed in the light of world events, and compared with pre-war figures. Details of some new processing plants are given, and measures required to ensure adequate future supplies are considered.—K. E. J.

ORES—MINING AND TREATMENT

The Evaluation of Ores. K. Sauer. (*Tech. Mitt.*, 1955, **4**, Dec., 210–217). Economic aspects of the use of ores are discussed. The iron content alone cannot be regarded as a means of evaluation. A high silica content requires large additions of limestone, thus increasing the amount of slag formed; this, in turn, requires more coke. Examples of calculations are given.—R. P.

How are Iron Ores to be Specified ? B. Pičman. (*Hutnické Listy*, 1956, **11**, (1), 10–17). [In Czech]. Detailed proposals for Standard Specifications relating to ore quality are made, based primarily upon particle size and coke consumption in the reduction in the blast-furnace.—P. F.

Mineralogy and Petrology of Lorraine Ironstones and their Beneficiation Possibilities. M. Deudon. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 2, 1–10). The constitution and composition of Lorraine iron ores are surveyed on a regional basis. The mineralogical constitution is shown to be the controlling factor for all methods of beneficiation and limitations of treatment prospects are discussed.—E. C.

Use of Hot Compressed Air at Kiruna. C. Westlund. (*Canad Min. J.*, 1956, **77**, Jan., 51–52). Recent underground extension of Kiruna mine, planned to provide 12 million tons of ore per year, is outlined, and the use of a decentralized hot compressed air system designed by Atlas Copco is described. This system avoids frozen condensate in low temperature conditions and improves comfort of operators.—T. E. D.

Equipment for Handling Imported Ores. (*Min. J.*, 1955, **245**, Nov. 25, 615; Dec. 2, 651). The speed and economy with which iron and manganese ores can be transported from ship

to quayside and quayside to the blast furnace are major factors affecting British iron and steel production. The results of recent investigations by BISRA are discussed.—B. G. B.

Concentration Tests of California Chromite Ores. A. L. Engel, E. S. Shedd, and E. Morrice. (*U.S. Bureau Mines Rep. Invest.* 5172, 1956, Jan.). The results of ore dressing tests on low grade chromite ores are given. Certain ores were concentrated to between 40 and 50% Cr_2O_3 with recoveries of 75% by gravity concentration.—B. G. B.

Pelletizing of Hematite Concentrates. F. Savioli and C. Mellere. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 3, 1–18). Details are given of Italian laboratory and pilot plant investigations of pelletizing hematite and limonite fines and concentrates. The work followed established lines of drum pelletizing and firing in a vertical shaft kiln with external combustion chamber. Process data and pellet properties are discussed and it is concluded that pelletizing is more economic than sintering. A 200-ton per day production plant is nearing completion.—E. C.

A New Formula for Particle Size Distribution of Products Produced by Comminution. J. Svensson. (*Acta Polytec.*, 1955, **4**, No. 6). A general formula for calculating this size distribution is presented and the results of extensive tests to compare the calculated and actual distribution are given.—B. G. B.

Some Results and Prospects in the Beneficiation of Iron Ores. I. N. Plaksine. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 1, 1–21). The influence of ore composition on selection of treatment is discussed. Ores are classified according to their mode of origin and methods of treatment are suggested for each type. The beneficiation of magnetite ores is dealt with in some detail, followed by a chapter on treatment of weakly or non-magnetic iron ores. Problems of iron ore flotation are discussed and an autoradiographic method is outlined for studying the interaction between flotation reagents and mineral surfaces.—E. C.

New Aspects of Burden Preparation for Blast Furnaces. A. Mercier. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 8, 1–19). A general survey of ore handling and preparation through all stages between mine and blast furnace is followed by a more detailed study of modern sintering practice. Reference is made to British, French, and German developments in summarizing the trend of present methods. A brief final chapter deals with rotary furnaces and pelletizing is mentioned.—E. C.

Concentration of Low Grade Ores at the Humboldt Mine. R. R. Smith. (*Blast Furn. Steel Plant*, 1956, **44**, Mar., 309–314). This plant in Michigan, U.S.A., processes low grade (33% Fe) specular haematite ore by froth flotation to yield a product containing over 62% Fe; only 44% of the original weight of mined ore is retained and shipped as concentrate. The output is approximately 250,000 tons of concentrate per year.—B. G. B.

Development of Economical Furnaces for the Magnetic Roasting Beneficiation of Ores. V. I. Karmazin. (*Stal'*, 1955, (8), 692–698). [In Russian]. The economics of the reduction-roasting-magnetic method of beneficiating iron ores are discussed and designs of suitable shaft and kiln furnaces are considered. Among the designs illustrated are those of experimental shaft and rotating kiln furnaces designed by the Ore-Mining Research Institute. It is concluded that, generally, the relatively high capital costs of this process are recouped by savings in blast-furnace operating costs.—S. K.

The Influence of Carbon Monoxide on the Process of Dehydration of Iron Ores. V. T. Bragin. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (4), 86–92). [In Russian]. The influence of atmosphere (air or carbon monoxide) on the velocity of dehydration of iron ores containing hydrated iron oxides was investigated. It was found that the dehydration process in the atmosphere of carbon monoxide is faster than in air. The velocity of evolution of hygroscopic water is independent of the nature of the atmosphere.—V. G.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf. Current Position of Iron Ore Pelletizing and Iron Ore Sintering, with Special Reference to Developments in Germany. K. Meyer (4–9). The relative merits of pelletizing and sintering are compared, with particular reference to German requirements. The factors to be considered in choosing between the two processes are discussed. **Technical Sessions in Liège. The Sintering of Iron Ore from the Luxembourg and Lorraine Ore Fields by the Dwight Lloyd Process and in Rotary Kilns.** J. Paquet. A comparison is given of results obtained by Dwight Lloyd and rotary kiln processes. Chemical and physical properties, economics, and general considerations are discussed, and it is concluded that the choice of process depends mainly on the cost of fuel available on site. Brief details of the new Terre Rouge plant are included.—G. F.

Concentration Tests of Selected California–Nevada Manganese Ores. A. L. Engel, H. J. Heinen, E. Morrice, and E. S. Shedd. (*U.S. Bur. Mines Rep. Invest.* No. 5163, 1955, Oct.). Tests carried out on the concentration of 9 low grade manganese ores are reported. The results indicate possible treatment methods and the limitations of these methods.—B. G. B.

Crushing by means of Impact Crushers and Beater Mills. M. Mortenson and H. J. Hansen. (*Tidsskr. Kjemi, Bergvesen Met.*, 1955, **15**, (8), 141–146). [In Norwegian]. Details are given of the operating principles of impact crushers, six different types being described. Norwegian tests using a Hazemage crusher on graphite, sulphide, and hematite ores are dealt with, information being given on the effects of speed variations and of changes in the size of the gap between the rotor and impact plates. Further sections discuss possibilities of selective crushing, impact plate wear, and the relative efficiencies of impact, disc, and jaw crushers.—G. G. K.

Fundamental Research on Pyrites Cinders as Pig-making Material. I. T. Akimoto and S. Onishi. (*Tetsu to Hagane*, 1955, **41**, Nov., 1155–1161). [In Japanese]. The following measurements were made on a series of cinders, to clarify reduction behaviour: efficiency of reduction by CO and pitch-coke; permeability at various high temperatures; surface appearance by electron microscopy; and surface area.—K. E. J.

Reduction of Iron Ores by Reformed Natural Gas. II. R. Sato and N. Tabata. (*Tetsu to Hagane*, 1955, **41**, Nov., 1149–1155). [In Japanese]. Long times are required for reduction of ore by natural gas at low temperature, but the reduction velocity increases when decomposition of hydrocarbons occurs. Additions of Na_2CO_3, $CaCO_3$, or CaO increased the reduction velocity, presumably by accelerating hydrocarbon decomposition.—K. E. J.

The Pelletizing Plant at Malmberget, Sweden. (*Min. J.*, 1955, **245**, Dec. 16, 708–709). A short account of this iron ore pelletizing plant which began operations in 1955 is presented. The plant is planned to produce pellets at a rate of 15 tons/hr (100,000 tons/year) but it is expected to reach a capacity of 20 tons/hr. Details of the balling drum and furnace are given.—B. G. B.

FUEL—PREPARATION. PROPERTIES, AND USES

The Theory of Flame Phenomena with a Chain Reaction. D. B. Spalding. (*Phil. Trans. Roy. Soc.*, 1956, Series A, **249**, Mar. 22). Three types of flame—spontaneous ignition, laminar-flame propagation, and homogeneous steady-flow reaction zone—have been studied. In these flames chain reactions are present and the results obtained are compared with single step reactions.—B. G. B.

An Analysis of the Stability of Carbon Monoxide–Hydrocarbon–Air Flames. A. Levy and P. F. Kurz. (*J. Amer. Chem. Soc.*, 1955, **77**, Mar. 20, 1459–1461). The binary fuel mixture burning in air has greater stability than either the carbon monoxide or the hydrocarbon burning alone in air. The postulate that CO–hydrocarbon may be transformed to CO–water vapour before entering the flame zone is supported by results showing agreement between stabilities of CO–water vapour and CO–hydrocarbon flames.—T. E. D.

Combustion Systems in Steel Plants. F. S. Bloom. (*Metal Progress*, 1955, **68**, Nov., 111–115, 200). The design of gas burners for blast furnace stoves, open-hearth furnaces, reheating furnaces, high-speed heating, and heat-treating furnaces is considered.—B. G. B.

Infra Red Absorption and Emission Spectra of Carbon Monoxide in the Region from 4 to 6 Microns. E. K. Plyler, L. R. Blaine, and E. D. Tidwell. (*J. Res. Nat. Bur. Stand.*, 1955, **55**, Oct., 183–189). The results of accurate measurements on CO and CO_2 are given. The complete emission spectra for the two gases between 4 and 6 microns are shown in two figures.—B. G. B.

Correlation of Equilibrium Atom and Free Radical Concentrations in Flames of Carbon Monoxide, Hydrocarbon and Air with Burning Velocities and Flame Stabilities. P. L. Walker. (*Fuel*, 1956, **35**, Apr., 146–152). A correlation between these

variables was found to be lacking for CO–propane–air mixtures and CO–CH_4–air mixtures.—B. G. B.

Heating Up Open Hearth Furnaces with Natural Gas. G. Grosvenor. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 237–243). The O.H. furnaces at the Pueblo Works of Colorado Fuel and Iron Corporation are heated up after rebuild by means of natural-gas burners installed in each checker chamber bulkhead. The author describes the type of burner used, outlines the advantages of the method, and quotes average heating times obtained.—G. F.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf. The Production of Iron-Rich "Iron-Coke" for Blast Furnace Operation. C. Eymann. (15–19). Bituminous coal, unsuitable for blast furnace coke production, can be successfully used as a binder for iron ore fines, producing a material suitable for blast furnace use. Details of the process are given. **Coke Properties and their Determination.** F. Wesemann. (24–27). A new index for the mechanical strength of metallurgical coke is suggested, and some of its advantages are outlined. **Flow in Iron and Steel Works.** M. Hansen. (91–94). Details are given of some of the instances in which model tests have contributed to the governing and controlling of aerodynamic flow problems in the iron and steel industry. **The Appraisal of the Efficiency of Hot-Blast Stoves.** K. Kessels. (95–99). Recent German research on the thermal appraisal of all types of hot-blast stove checkerwork is described. The work furnishes a basis of comparison for determining the flow-resistance and load characteristics of the brickwork.

Technical Sessions in Paris. Application of Theoretical Studies of the Radiation of Flames to the Metallurgy of Iron and Steel. M. Michaud and G. Husson. Some of the conclusions of the flame radiation research at Ijmuiden are enumerated, and brief details given of IRSID investigations into the application of these conclusions. **Hot Blast Stoves.** D. Sanna. A brief description is given of a study of the efficiency of hot blast stoves, considered both as heat exchangers and as heat storage units. The results of a survey of flue-gas and hot-blast flow and of heat transfer are outlined. **The Metallurgical Coke-Tests.** J. Thibaut. The author considers the following to be the most essential characteristics of metallurgical coke: optimum lump size; porosity and homogeneity; good cohesion; and low density. **Policy of Full Utilization of Calories in the Iron and Steel Industry of the Basin of Lorraine.** M. Morizot. The author surveys the advantages derived by the steelworks of the Lorraine Basin from the establishment of a common power station.—G. F.

Steam and Power in the Gas and Coking Industries. L. J. Clark. (*J. Inst. Fuel*, 1956, **29**, Mar., 106–128). Based on the experience of the North Thames Gas Board, an outline is given of recent trends in the steam and power demands of gasworks, and methods of effecting economies in fuel are described. The advantages of various types of prime movers are compared. Many illustrated examples are given.—D. L. C. P.

The Utilisation of Blast Furnace Gas for Generating Electric Power with Gas Engines. P. J. Brulhet. (*Centenary Congress of the Société de l'Industrie Minérale*, 1955, June, Sf10, 1–19). Details of power generation with gas engines are discussed and advantages in thermal efficiency and capital outlay are stressed. Flexibility available through a chain of medium-sized power stations is advocated. The shortcomings of gas engines are analysed and intensified research and development are suggested to reduce high maintenance requirements and to bring gas engines up to date.—E. C.

Applications of the Gas Turbine in the Iron and Steel Industry. F. Huber. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf8, 1–11). General principles of gas turbine operation are described and various applications in iron and steel works are discussed. Particular reference is made to two open cycle turbines running on blast furnace gas in Lorraine. Great scope is suggested for using gas turbines for blast furnace blowers.—E. C.

High Temperature Steels and Their Use in the Construction of High Temperature Recuperators. P. Villain. (*Chaleur et Ind.*, 1956, **37**, Jan., 3–10). The properties required of metals for use in high temperature recuperators are discussed, and the metals used by S.E.T.R.E.M. in their construction are listed. The following properties of these metals are examined: resistance to oxidation at elevated temperatures, the ease with which tubes can be produced, mechanical resistance to heat, changes occurring in the structure after long periods at high temperatures, dilation and weldability.—T. E. D.

Steel Recuperators for Two Pusher Type Slab Reheating Furnaces. F. M. Kofler. (*Chaleur et Ind.*, 1956, **37**, Feb., 45–50). Two three-zone 100-ton Rust pusher type furnaces, built by Ofenbau-Union G.m.b.H. in collaboration with Stein et Roubaix, for August Thyssen-Hutte at Duisburg-Hamborn are described. The steel recuperators, for preheating the combustion air, constructed by Rekuperator K.G., Dr. Ing. Schack et Cie., Düsseldorf, are described in detail.—T. E. D.

Advantages and Disadvantages of Metallic Recuperators Used at the Appleby-Frodingham Steelworks. N. H. Turner. (*Chaleur et Ind.*, 1956, **37**, Feb., 39–41). Some of the troubles encountered in using the recuperators are described and the reasons are examined, with particular attention to carbon deposition. General observations on installation and operation are included.—T. E. D.

Organic Sulphur in Coal. J. D. Brooks. (*J. Inst. Fuel*, 1956, **29**, Feb., 82–85). A critical survey is made of published work on organic sulphur in coal, with special reference to observed correlation between organic sulphur and other characteristics such as coking properties.—D. L. C. P.

Evaluation of the Performance and Design of Cyclone Separators on the Basis of Recent Researches. W. Barth. (*BWK*, 1956, **8**, (1), 1–9).

Application of the Granulometric Index to the Study of the Mixer-Grinder. P. Delong. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1956, **13**, (1), 143–145). The index proposed by Burstlein is used to relate size distribution to time of mixing.

Production of Metallurgical Coke: Continental Developments in the Wider Use of Non-Coking Coals. (*Iron Coal Trades Rev.*, 1955, **171**, Dec. 30, 1599–1602, 1598). Details are given of the Longwy-Burstlein process which permits the production of metallurgical coke from coal mixtures which ordinarily do not possess coking qualities. The process is essentially a system of controlled and selective grinding and screening, ensuring a final mixture with the desired particle size and petrographic distribution.—G. F.

The Gas Balance for the Lorraine Region 1955-1957. Long Distance Gas Transmission. J. Serre. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sa. 19, 1–10). The actual and potential production of coke oven and blast furnace gas in Lorraine are outlined and intensified high-pressure long-distance transmission is urged to help industrial expansion.—E. C.

Comparison of Different Methods of Atomizing Fuel Oil in an Open-Hearth Furnace. G. Husson, A. Peters, G. Jomier, and R. Kissel. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 7, 1–15. *Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 3, 555–568). The instrumentation on an open-hearth furnace is described. This included suction pyrometers for combustion air temperature, oxygen recorder for oxygen content of waste gases, and radiation pyrometer for temperature of the upper part of the recuperator. Using these instruments it was possible to study the effect of variations in oil atomization with various pressures of steam or air. The results are discussed in relation to melting rate.—T. E. D.

TEMPERATURE MEASUREMENT AND CONTROL

Radiation Pyrometers for the Measurement of Transient Temperatures. R. Chion. (*Métaux–Corrosion–Indust.*, 1956, **31**, Jan., 22–37). A review is made of techniques for the measurement of transient temperatures such as occur in flames.—B. G. B.

Methods of Determining and Compensating Errors in Heat Measurements. M. Tesio. (*Calore*, 1955, **26**, Nov., 516–525). [In Italian]. The author gives a brief review of the fundamentals of the theory of errors. This essential part of every engineer's and scientist's intellectual equipment is frequently neglected in Anglo-Saxon countries where it is considered a branch of theoretical statistics. The author describes the different types of error avoidable, systematic and accidental, discusses direct and indirect measurements and shows how to determine the minimum error and how to compensate for errors.—M. D. J. B.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf. Present State of Temperature Measurement and Control of Steel Melts in the Furnace and During Teeming. K. Guthmann. (34–39). The author describes German instruments for temperature measurement, including the immersion thermocouple and the optical and

colour pyrometers. The importance of the colour pyrometer in quality control, particularly when allied with the immersion couple, is emphasized.—G. F.

Some Suggestions Concerning the Maintenance of Pyrometers. L. Walter. (*Chaleur et Ind.*, 1955, **36**, Dec., 370–374). Use, installation, protection, and checking of the various types of pyrometers are outlined.—T. E. D.

Temperature Measurement and Control. W. Weber. (*Härterei-Tech. Mitt.*, 1944, **3**, 39–50). Various pyrometers, methods of measurement and control of temperature are described.—R. P.

Longer Life for Chromel–Alumel Thermocouples. N. F. Spooner and J. M. Thomas. (*Metal Progress*, 1955, **68**, Nov., 81–85). Errors that develop in Chromel–Alumel thermocouples enclosed in long narrow protection tubes can be minimized or eliminated by hermetically sealing the assembly and inserting titanium wire as an oxygen 'getter.'—B. G. B.

REFRACTORY MATERIALS

Quartz–Cristobalite Transformation. I. Effect of Surface Area on Transformation of Quartzite Rocks. H-E. Schwiete and H. Stollenwerk. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 583–587). The authors describe measurements of specific gravity, and radiological investigations of the effects of grain size and surface area on the transformation of quartzite rocks at temperatures of 1200 to 1500°.—A. C.

The Use of Synthetic Resins for Thermal Insulation at High and Low Temperatures. R. Lazzerini. (*Calore*, 1955, **26**, Oct., 455–474). [In Italian]. The author examines the general properties of plastic materials and in particular their thermal characteristics and mechanical properties with a view to their insulating properties at high and low temperatures. A detailed review is given of the various groups of modern plastics and their applications. (36 references).—M. D. J. B.

Note on the Comparison of Insulating Bricks from the Point of View of Their Usefulness. J. François. (*Chaleur et Ind.*, 1955, **36**, Dec., 357–364). An attempt is made to regularize the way in which the characteristics of an insulating brick are expressed. The factors influencing the performance of the brick are listed. A simple method of measuring thermal conductivity is outlined.—T. E. D.

Experience with the Linings of Core-less Low Frequency Induction Crucible Melting Furnaces. H. Rohn. (*Giesserei*, 1956, **43**, Jan. 19, 40–43). The suitability, working, and life of plastic refractory sand, quartzite, and magnesite ramming masses for this type of furnace are described and compared. Works results are quoted for the melting of cast iron, steel, and light metals. Amongst others, economic aspects are considered.—R. J. W.

Recent Developments in Refractories for Iron and Steel Industry. Y. Kora. (*Tetsu to Hagane*, 1955, **41**, July, 817–822). [In Japanese]. Developments surveyed include basic bricks for open-hearth furnaces, super-duty silica bricks, casting refractories, fireclay bricks for checkers, carbon linings for blast furnaces, improvements in manufacturing methods, etc.

Practical Suggestions for Speeding Placement of Castable Refractory. N. M. Thompson. (*Indust. Heating*, 1955, **22**, Oct., 2134–2146). Design data for the construction of large monolithic refractory concrete sections are given.—A. D. H.

Drying Rates in Infra-red Drying of Clay. D. Woo, H. P. Simons, and P. R. Jones. (*J. Amer. Ceram. Soc.*, 1955, **38**, Nov., 383–388). Equations are deduced showing the effect of several variables on the drying rates of clay under infra-red lamps.—D. L. C. P.

Tridymitic Silica and its Production. R. Bárta and K. Špičák. (*Hutnické Listy*, 1955, **10**, (12), 709–715). [In Czech]. The method of production of brown-coloured high-quality silica made in a new plant from local resources is described. The properties of bricks for blast furnace linings made from this material were studied. The tridymite content is about 30%.—P. F.

The Practical Interpretation of Some Physical Characteristics of Alumino-Silicate Refractory Products. M. Demarteau. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Dec., 669–673). The application of the results of laboratory tests on refractory materials of this class to service conditions is discussed in some detail.—B. G. B.

Comparison of Modulus of Rupture Values Obtained Using Center- and Third-Point Loading. A. J. Metzger and F. W. Thompson. (*Amer. Ceram. Soc. Bull.*, 1955, **34**, Dec., 415–418). 245 fireclay bricks of various types were tested in flexure using centre-point and third point loading; no significant differences in variability of moduli of rupture values between the 2 methods of loading were found.—D. L. C. P.

Thermodynamic Data on Oxides at Elevated Temperatures. H. P. Tripp and B. W. King. (*J. Amer. Ceram. Soc.*, 1955, **38**, Dec., 432–437). An extensive compilation of data on the free energy of formation of oxides is presented in graphic form. From the curves it is possible to obtain the free energy of most ceramic oxides in the temperature range 0° to 2400° C.—D. L. C. P.

New Method of Preparing Clay Samples for Differential Thermal Analysis. J. D. Walton. (*J. Amer. Ceram. Soc.*, 1955, **38**, Dec., 438–443). In the method described the specimen and reference sample are in the form of pellets, supported by the thermocouples in the furnace atmosphere. Results from this technique are compared with those when the materials were contained in an Inconel block; the new method showed considerably better sensitivity below 400° C, but this advantage fell off towards 1000° C.—D. L. C. P.

Study on the Corrosion of Pouring-Pit Refractories by the Molten Steels and Slags. II. S. Maekawa and Y. Nakagawa. (*Tetsu to Hagane*, 1956, **42**, Jan., 8–14). [In Japanese]. Corrosion of runner refractories is strongly influenced by oxygen in the atmosphere and oxides of iron and manganese in the molten steel promote corrosion. Less corrosion is produced by acid than basic open-hearth steel—K. E. J.

A Resumé of Blast Furnace Refractories. H. Kramer. (*Blast Furn. Steel Plant*, 1956, **44**, Jan., 55–60). The properties and selection of blast furnace refractories are discussed with particular reference to service performance. The results of temperature measurements made on blast furnaces during drying out and blowing in are described. Very high rates of heating during blowing in have been observed and these high rates of heating are known to cause severe damage to bricks under laboratory conditions. The author considers that the long period of drying out can be shortened and that the short period of blowing in should be extended.—B. G. B.

A Malleable Furnace Refractory Cost Reduction Programme. F. J. Pfarr and A. S. Johnson. (*Trans. Amer. Found. Soc.*, 1955, **63**, 657–661). Refractory problems in malleable iron air furnaces are discussed in general terms and details are given of the life and cost of side-walls constructed by three different methods.—B. C. W.

Improving Refractory Cost in Malleable Melting. L. E. Emery. (*Trans. Amer. Found. Soc.*, 1955, **63**, 589–595). The selection for, and installation of refractories in an air furnace, cupola and ladle at the Marion Malleable Iron Works, Marion, Ind., is described and discussed.—B. C. W.

Application of Refractories in the Foundry. F. H. Fanning. (*Trans. Amer. Found. Soc.*, 1955, **63**, 195–198). The principal methods of making high- and super-duty fireclay bricks and high-alumina bricks are briefly described and foundry applications for bricks made by the different processes are reviewed.

The Choice of Refractories for the Iron and Steel Industry. L. Antonio de Araujo. (*Bol. Assoc. Brasil Met.*, 1955, **11**, July, 315–323). [In Portuguese]. The author lists the types of refractories most frequently used in the iron and steel industry and for each gives a brief discussion of service requirements and the chemical and physical properties desirable. (10 references).—P. S.

Fettling a New Hearth on a Large Open-Hearth Furnace with a Basic Roof. V. O. Kulikov and I. I. Bornatskii. (*Stal'*, 1955, (7), 597–600). [In Russian]. An account is given of the fettling of a new hearth in a 370-ton all-basic O.H. furnace and of the chemical and petrographic examination of the thirteen fettled layers. The fettling mixture consisted of magnesite, O.H. slag and scale. It was found that with a roof temperature of 1650–1700° C the compositions of the layers from four to twelve, inclusive, differed regularly from those calculated, the MgO-content being higher and the CaO- and SiO_2-contents being lower. The refractoriness of the first fettled layer was 1870° C, that of the others being > 1900° C. The use of the all-basic construction has resulted in considerable reductions of hot-repair time. 1700° C is the highest advisable roof-temperature for fettling.—S. K.

Insulating Fire Brick Can Cut Production and Fuel Costs. J. E. Brinckerhoff. (*Indust. Heating*, 1955, **22**, Oct., 2123–2132, 2149). The thermal properties, uses, and advantages of insulating firebricks are given.—A. D. H.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

DEMAG-Humboldt Low-shaft Furnace Process. H. Reinfeld. (*Demag News*, 1955, (140), 16–25). The present stage of development of the single-stage low-shaft furnace is described and results obtained during recent years on German home ores and foreign ores using non-coking coal are discussed. The results are said to justify the process for industrial application.—B. G. B.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf. The Demag–Humboldt Low Shaft Furnace Process. E. Hofmann. (9–15). The author describes the essential characteristics of the Demag–Humboldt low-shaft furnace process and discusses the nature and form of the raw materials used. The design and layout of the pilot-plant at Köln-Kalk are described.

Technical Sessions in Liège. A Summary of Research Results Obtained on the Low-Shaft Furnace to Date. J. Wurth. A description is given of the experimental low-shaft furnace at Ougree and the objects of the research are outlined. The results obtained to date are summarized.—G. F.

The Stack Shell of the Blast Furnace. Some Operating Results. M. A. Heczko. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 3, 539–548). The practice of using stack bands is mentioned and their construction is illustrated. Performance of three furnaces, one with a steel plate shell cooled throughout with sprays, one with cast iron plate coolers, and one with copper plate coolers are compared, and cooler design is illustrated. The effect of zinc in the burden on the refractory is discussed in relation to stack design.

Inquiry into Hot Blast Valves. L. Chatet. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1956, **13**, No. 3, 549–554). The items in a questionnaire on hot blast valves are listed, covering design, cooling, performance, etc. The answers from 16 works are surveyed and discussed. It is concluded that the use of purified water for cooling was the chief requirement for long life. Dimensions, seating design, position, method of cooling, materials of construction and conditions of service are discussed, and recommendations are made.—T. E. D.

The Design of Blast Furnaces with Thin-walled Shafts. S. Černoch. (*Neue Hütte*, 1955, **1**, Dec., 66–77). Thin walled furnaces were first built in Czechoslovakia, in 1926. They are still preferred to thick-walled furnaces. The latest models are welded; the circulation of jacket water has been improved; longer life and lower coke consumption is claimed for them.

The Production of Pig Iron in Low-Shaft Furnaces. I. P. Bardin. (*Stal'*, 1955, (4), 376–381). [In Russian]. After an outline of the development of the low-shaft blast-furnace in East Germany, the operation of the battery now working is discussed, compared with that of a coke blast-furnace and a small coal blast-furnace, the hearth diameters being 6·2 and 1·5 m respectively. The present state of development is considered to justify its adoption on a relatively small scale in those parts of the U.S.S.R. where cheap non-metallurgical fuel is available, and this process is also suitable for the production of special pig irons.—S. K.

Mechanical Casting of Pig Iron and Non-Ferrous Metals. C. H. L. Schneider. (*Demag News*, 1955, (140), 8–16). A survey of the current stage of development and merits of the various types of casting machines is presented.—B. G. B.

The Modern Blast Furnace. R. Petitjean. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 13, 1–3). A very brief account is given of recent developments in blast furnace equipment.—E. C.

The Modern Blast Furnace. J. Vibrac. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 12, 1–19). A detailed survey is made of the design, construction, and equipment of the modern blast furnace and ancillary plant.

Materials for Coating Pig-Casting Machine Moulds. A. G. Romanenko. (*Stal'*, 1955, (8), 753). [In Russian]. Advantageous results have been obtained from the use of a wash containing finely divided coal, coke, fireclay, and lime for spraying pig-casting machine moulds.—S. K.

The Joint Stresses in the Steel Structure and the Lining of Blast Furnaces. L. A. Sorokin. (*Stal'*, 1955, (8), 698–703). [In Russian]. An analysis of stresses set up by the different behaviours of the steel shell, coolers, and lining of a blast furnace is carried out, and the equations obtained are applied to blast-furnace design problems. A design in which diffusion of zinc vapours into the lining is avoided by the use of compressed gas is described.—S. K.

Creep Tests on Cowper Stove Checkers. J. Baron. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf. 5, 1–10). An outline is given of the creep of refractories under load and its effects on checker performance. The results of series of creep tests on various grades of checker brick are described and discussed.—E. C.

Facts on a New Concept in Blast Furnace Blowers. W. Karrer. (*Centenary Congress of the Société de l'Industrie Minérale*, 1955, June, Sf. 9, 1–14). A detailed survey reviews all aspects of the use of gas turbines for blast furnace blowers, on the basis of a specific example from Lorraine. Great technical and economic advantages are claimed.—E. C.

A Contribution on the Use of Crushing and Sizing of the Blast Furnace Burden. A. Moutot. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 9, 1–24). On the basis of a considerable range of French blast furnace trials with prepared burdens the beneficial effects of preparation are discussed with regard to sulphur removal, improved indirect reduction, raised throughput and lower coke rates. Layer charging is advocated together with the use of considerable proportions of minus 10 mesh material and the economics of burden preparation are discussed.—E. C.

Mothballing a Blast Furnace. F. R. Kik. (*Blast Furn. Steel Plant*, 1956, **44**, Feb., 208–214). Experiences gained at the Inland Steel Co., U.S.A., in the sealing of the bosh area of blast furnaces during banking up are described. Very successful results have been obtained using strippable weather-tight plastic coatings of the type used for the storage of warships. The coating can be applied by a spray gun. After banking for 55 days the stockline had dropped by only two feet indicating that little of the coke was able to burn.—B. G. B.

The Use of Radioactive Isotopes for Determining the Wear and Tear of the Refractory Lining of a Blast Furnace. R. Mintrop and E. Roemer. (*Tech. Mitt.*, 1955, **4**, Dec., 218–224). The construction of a suitable furnace is described. Cobalt 60 is incorporated in the refractory lining and any change in thickness of the lining is thus detected, using the gamma radiation.—R. P.

The Measurement of Gas Transit Times in a Blast-furnace. T. W. Johnson. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 18–22). [This issue].

The Why and How of Oxygen–Air Blast for Iron Furnaces. J. G. Platon. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 11, 1–10). The principles and practice are discussed of using blast with considerable oxygen enrichment. It is held that cold blast must be used and that the specific furnace performance can be increased significantly, accompanied by a reduction in pig iron cost.—E. C.

The Theory and Application of Thermo-Dynamic Equilibrium of the Blast Furnace. J. Raick. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 10, 1–22). The present state of knowledge of blast furnace thermodynamics is surveyed and discussed. Conditions are deduced for optimum utilization of heat and carbon in the various parts of the furnace and practical applications for most economical furnace practice are deduced.—E. C.

A Study of the Distribution of Gas Stream in a Blast Furnace Using a Model. N. N. Chernov. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (1), 80–91). [In Russian]. Modelling conditions of the movement of a gas stream in a blast furnace are discussed. The dependence of the distribution of the gas stream between three annular sections of a blast furnace of equal outlet area, peripheral, intermediate and central on size distribution of the burden, blast volume and the extension of tuyeres towards the centre of the furnace was investigated using a 1/25 scale model. The results obtained indicated that the size distribution of the burden is the predominant factor influencing the distribution of the gas stream. Blast volume, extension of tuyeres towards the furnace centre and their diameter are only of secondary importance. The influence of the mass-velocity of the blast increases with increasing size of the burden. In the case of a lumpy burden the maximum amount of gas passes through the intermediate zone and the minimum at walls. With a burden of normal size distribution 37% of gas passes through the peripheral zone, 33% in the intermediate zone and 30% in the central zone. Therefore in order to increase the gas flow in the centre of the furnace, an increase in the blast volume, tuyeres extension and a decrease in their diameter

are insufficient, but an increase of the size of the burden in the centre is necessary. With a lumpy burden the influence of the above factors considerably increases. The distribution of static pressure along the radius at a given level depends on the size distribution of the burden. The pressure difference at a given level increases with decreasing size of the burden.

Processes Taking Place in the Blast Furnace Bosh. I. P. Bardin and M. Ya. Ostroukhov. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (3), 72–82). [In Russian]. Measurements of temperatures and analyses of samples of materials and gas withdrawn from the bosh of a blast furnace along three different radii during the production of foundry and basic iron were carried out. It was found that when making basic and sometimes also foundry iron (cold working) the accumulation of ore in the bosh produces low temperatures in the annulus 20–60 in. from the bosh walls. Gas composition also corresponds to temperature distribution in the bosh. The greatest flow of pig iron and slag was observed in the peripheral zone of the bosh. Only during very hot working (foundry iron) were the iron and slag over the whole radius (80 in.) in the liquid state and approximately of their final compositions.—V. G.

The Boudouard Equilibrium in the Blast Furnace. W. v. Preen. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1582–1583). A method is given for obtaining the equilibrium condition in any blast furnace so that the gas composition may be calculated.—A. C.

Effect of Pressure on the Movement of Gases in the Blast Furnace. M. A. Stefanovich. (*Stal'*, 1955, (5), 398–407). [In Russian]. Based on theory and on observations made on several Soviet furnaces operating at normal and elevated pressures, a detailed analysis is presented of the effects of high top pressures on furnace working and operation. It is shown that the pressure drop in a blast furnace is inversely proportional to gas pressure for constant distribution and state of the stock column. Increasing gas pressure is accompanied by decreases in the angles of repose of burden and coke, the size of the charge lumps at the periphery and the extent of channeling, while the quantity of fines left in the furnace, particularly at the periphery, increases. For this reason pressure increases are most effective for furnaces smelting prepared charges. For high top-pressure operation charging should be changed so as to keep fines away from the walls and the throat diameter should be decreased; raw-material preparation retains its importance.—S. K.

Blast Furnace Operation with Ores of Low Bulk Density. L. Z. Khudak and Yu. A. Popov. (*Stal'*, 1955, (5), 408–417). [In Russian]. A comprehensive account is given of experience at the Chelyabinsk Metallurgical works on the smelting of lean, low bulk-density, dusty ores. On basic practice the volume of the burden exceeded that of the coke, leading to considerable redistribution of materials at the stockline and concentration of fines at the centre, to excesses of ore at the centre resulting in peripheral working, a condition which could not be corrected, and the uneven working facilitated scaffold-growth. Control from the top was limited to securing an adequate peripheral flow of gas. The lowest temperatures were observed in the central part of the stack, but the hearth worked normally. The use of the ores was least disadvantageous when making ferrosilicon. It is considered that better results would have been obtained in a lower furnace with reduced stack batter.—S. K.

Energy Problems of Blast-Furnace Operation at Elevated Pressure. N. E. Kunakov. (*Stal'*, 1955, (7), 637–639). [In Russian]. The effects of using high top pressure on the operation of the blast furnace and ancillary plant are discussed on the basis of accumulated experience and calculation. The following are among recommendations made for existing works adopting high top pressure operation: Use of the additional energy of the top gas for improving the efficiency of available gas-cleaning plant and to enable better plant to be adopted; increase in the mains pressure; operation of gas-using furnaces with injector burners; and for new and reconstructed works the quicker development of improved dry cleaning methods to reduce dust content of gas at 200–250° C to 8–10 mg/m^3 and the greater use of heat exchange.—S. K.

The Behaviour of Sulphur in Blast-Furnace Smelting and Ways of Reducing the Sulphur-Content of Pig Iron. V. G. Voskoboinikov. (*Stal'*, 1955, (7), 583–591). [In Russian]. Original and available information on the distribution of sulphur between metal, slag and gas in the blast furnace is considered, and experiments on the desulphurization of pig iron outside the furnace are described. Although the elimination of more than 50% of the total sulphur through the furnace top can be achieved by suitable choice of operating conditions, the resulting decrease in efficiency would be prohibitive in ordinary, but might be acceptable in low-shaft, blast furnace practice. By means of data presented the calculation of true sulphur content of the iron and other problems can be solved. Examples showing good agreement between calculated and actual values are presented. It is suggested that the influence of temperature on the desulphurizing power of slags, although substantial, has previously been exaggerated. By the use of soda ash (0·8–1·0% of weight of metal) about 50% of the sulphur can be removed from normal foundry iron at the blast furnace plant, but it is recommended that the desulphurization is better effected in the foundry. Several substitutes for soda ash in external desulphurization are discussed and results of tests and plant drawings are presented. Latest evidence suggests that magnesium is a good external desulphurizing agent.—S. K.

The Evaluation of the Distribution of the Gas Stream from Gas Temperatures in the Off-Takes. A. B. Shur. (*Stal'*, 1955, (7), 592–597). [In Russian]. Some recent work and views on the relation between gas-flow distribution at the stock line of a blast furnace and gas temperatures in the off-takes is considered. Typical temperature recordings obtained during furnace-working with different degrees of packing of the charge at the periphery and with differing degrees of uniformity of peripheral distribution of solids and gas are examined. Ways of influencing conditions in the stock column and the effects of charging conditions on top-gas temperature are discussed. Suggested rules for deducing gas distribution from temperature records are summarized.—S. K.

Production of Pig Iron in Electric Smelting Furnaces. B. Marinček. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1426–1432). The use of electrical energy is compared with the use of the energy of coal. The conditions for reduction, current consumption, and the possibility of diminishing energy and coal requirements are mentioned, as well as methods of raising production and the use of cheaper raw materials. The utilization of slag and flue gas is referred to, and allusion made to large electrical furnaces.—A. C.

Smelting Iron Ore with Anthracite: Bureau of Mines Experimental Blast Furnace. R. C. Buehl and M. B. Royer. (*U.S. Bur. Mines Rep. Invest.*, No. 5165, 1955, Aug.). Tests carried out on an experimental blast furnace, with a 3 ft dia. hearth, to study the replacement of coke in the burden by anthracite are reported. The tests were performed over a period of two weeks and the furnace operated well with anthracite in amounts up to 40% of the total fuel and produced metal with a low sulphur (0·02%) and normal silicon (1·8%) content. An increase to 50% anthracite resulted in poor operation and hanging.—B. G. B.

TREATMENT AND USE OF SLAGS

Aluminous Blast-Furnace Slag for the Aluminium and Portland Cement Industry. O. Vorwerk, P. Hüttemann, and R. Mintrop. (*Tech. Mitt.*, 1955, **4**, Dec., 197–209). Present-day uses of furnace slags are discussed and phase diagrams given. The Séailles process for extracting pure alumina from basic slags is described. The residue can be used for Portland cement.—R. P.

Production and Uses of Foamed Blast Furnace Slag. W. Ruopp. (*Tech. Mitt.*, 1955, **4**, Dec., 225–236). A method for producing foamed slag from foundry slag is described whereby the foaming agent is added to the fluid slag under pressure. Temperature, viscosity, and surface tension of the melt will influence the structure of the product and also the behaviour of the slag. The final product is a suitable addition to structural concrete. (25 references).—R. P.

The Use of Blast-Furnace Slag as a Concrete Aggregate. E. F. Farrington. (*Proc. Inst. Civil Eng.*, 1956, **5**, Part 2, Jan., 56–59). The author discusses the successful use of blast furnace slag at the Appleby-Frodingham Steel Company for concrete aggregate. The slag conforms to B.S. 1047: 1952 and it is considered that any iron blast furnace slag which conforms to this specification may be suitable as a coarse aggregate for concrete making.—B. G. B.

The Properties of Blast-Furnace Cements Interpreted by Means of the Ternary Equilibrium Diagram "Slag Sand–Clinker–Gypsum." W. Kramer. (*Silicates Indust.*, 1956, **21**,

Jan., 20–28). [In German]. After reviewing the principles controlling the utilization of the system granulated slag–clinker–gypsum for cement production, experiments on the crushing and bending strengths on samples containing varying proportions of the three constituents are described and the results discussed. The setting process was studied on a mixture having a CaO/SiO_2 ratio of 1·45, with 14% alumina. The onset of hardening and the beginning of tear-formation are represented by lines in the ternary composition diagram.

Manganese from Steel-Plant Slags by a Lime-Clinkering and Carbonate-Leaching Process. II. Pilot-Plant Development. R. A. Heindl, J. A. Ruppert, M. L. Skow, and J. E. Conley. (*U.S. Bur. Mines Rep. Invest.*, No. 5142, 1955, Sept.). The process which has been developed from the laboratory to the pilot-plant scale has been shown to be technically feasible and could be scaled up to a commercial size production unit. The slag is clinkered with limestone under oxidizing conditions and the clinkers are subsequently reduced with hydrogen. The manganese is then extracted by leaching with ammonium carbonate solution. The solution is evaporated and crystalline material containing 66% manganese on calcination is produced.—B. G. B.

Surface Tensions of Silicates. R. E. Boni and G. Derge. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Jan., Section 1, 53–59). The authors discuss methods of measuring the surface tension of molten silicates and consider the applications of such measurements to problems of metallurgical interest. A relation between cation–oxygen attraction and surface tension and its temperature coefficient is shown, indicating the ionic nature of silicate melts.—G. F.

DIRECT PROCESSES

Development Trends in Metallurgical Reduction Processes. F. Johannsen. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 4, 1–8). A broad survey is made of methods and future trends in the production of metallic iron from ores. Included are developments in blast furnace practice, direct reduction processes, low shaft furnace trials, sponge iron production, the Krupp-Renn process, and experiments with reverberatory furnaces.—E. C.

Sponge Iron Production Today. J. Stålhed. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 5, 1–14). An account is given of principles and processes of present-day methods of sponge iron production, including the Wiberg, Höganäs, and Kalling-Domnarfvet process and various modifications and variations of these. The preparation of ores by pelletizing is discussed, also the use of sponge iron for steel making and for powder metallurgy.—E. C.

Non-Conventional Methods of Reducing Iron Ores. Application to French Ores. J. Astier. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 6, 1–22). All processes of ore reduction, other than conventional blast furnace methods, are considered and compared in a broad general survey. Principles are outlined in each case and advantages and limitations are discussed. Comparable processes and their economics are tabulated. (114 references).

The Basset Process of Simultaneous Production of Pig Iron and Cement in a Rotary Furnace. G. Pinot. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sb. 7, 1–10). The process uses a rotary furnace similar to a cement kiln to produce liquid iron and cement clinker from a pulverized mixture of ore, coal, and limestone. Details are given of the system which has been in operation successfully for some years in a number of plants.—E. C.

PRODUCTION OF STEEL

Problems and Trends in the Use of Iron and Steel Scrap in the United States. N. B. Melcher. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 3, 1–15). Details are given of the development of scrap consumption and of the respective problems of using scrap in open hearth, electric and blast furnaces, and in iron foundries. The increasing problem of contamination by residual metals is discussed in brief.—E. C.

Trends in Steelmaking Processes in the United States. J. C. O. Harris. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 1, 1–12). Present developments and future trends are covered in a broad survey with dominant attention to open hearth processes. Details are given of trials with oxygen blowing and the lance injection method. The less dominant converter and electric furnace practices are also discussed.—E. C.

The Tata Iron and Steel Company, Ltd. Steel Maker for India Since 1911 Now Expanding. L. N. Collins. (*Blast Furn. Steel Plant*, 1956, **44**, Feb., 178–198). A comprehensive illustrated account of this integrated steelworks 150 miles from Calcutta is presented. The present capacity is 750,000 tons of finished steel per year. Development programmes will increase this to 2,000,000 tons. At present there are 5 blast furnaces (two 22 ft 6 in. hearth dia., two 20 ft 6 in. hearth dia., and one 17 ft 6 in. hearth dia.) with a combined daily output of 4,200 tons of basic pig iron. The furnaces operate with 27% Al_2O_3 in the slag. There are three melting shops; the first consists of 8 open hearth furnaces and two 5-ton electric furnaces, the second of acid Bessemer converters and three tilting open hearth furnaces, the third of two 50-ton open hearth furnaces and one 25-ton acid converter. Details of the rolling mills are given; these include sheet bar and billet mill, 28 in. rail and structural mill, semi-continuous merchant mill, sheet mill and plate mill.—B. G. B.

Steelmaking Developments During the Past Decade. K. L. Fetters. (*Reg. Techn. Meet. Amer. Iron Steel Inst.*, 1955, 25–36). The author discusses the increase in steel production during the past decade and indicates that 80% of the increase can be attributed to increased heat sizes and the remaining 20% to improvements in practice. Some of these improvements are reviewed briefly.—G. F.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf: The Use of Oxygen to Speed Up the Oxidizing Process. H. Kosmider. (29–34). The oxygen requirements of the open-hearth and converter steelmaking processes are compared, and factors affecting the speed of conversion are discussed. **On the Development of Vertical Continuous Casting of Steel.** K. G. Speith and A. Bungeroth. (39–47). The advantages and disadvantages of continuous casting are reviewed, and factors affecting the throughput rate are discussed. Problems connected with casting direct from holding furnaces, and from tilting and stoppered ladles, are considered.

Technical Sessions in Liège. The Relative Merits of Enrichment of the Blast with Oxygen or of Blowing with Oxygen and Steam. F. Vandestrick. The economic and thermal aspects of oxygen-enrichment and oxygen-steam blowing in the basic converter process are discussed, and results obtained are reviewed. They show that these methods of blowing can widely extend the field of application of converter steels. **The Development of the Basic Bessemer Steel. I. Steel Processing.** P. Coheur and H. Kosmider. **II. On Some Cold Working Properties.** A. Desoer, F. Vandestrick, and J. Wurth. Reprinted from *Acier, Stahl, Steel*, March and May, 1955 (International Review for the Development of Uses of Steel, Brussels).

Technical Sessions in Paris. Causes and Control of Foaming or Emulsionized Blast Furnace and Open Hearth Slags. P. Kocakevitch. The author discusses the probable causes of foaming slags and of the formation of metallic emulsions in slags, and suggests possible means of controlling these phenomena. **Treatment of Steel by Mixing with Molten Slag.** R. Perrin. The author summarizes the results obtained in steelmaking and ferro-alloy manufacture, using the Perrin process of mixing with molten slags. Possible new applications of the process are indicated. **The Problem of Refining Phosphorus Pig Iron and Thomas Steel with Low Metalloid Contents.** N. Allard and G. Husson. Recent developments in the converter process refining phosphoric pig iron are summarized. They are concerned mainly with greater uniformity in manufacture, in particular with determination of the end of the blow, and with reduction in phosphorus and nitrogen contents. **Continuous Steel Casting.** J. Seloron. The author discusses the technical aspects of some of the problems of continuous casting of steel, and considers the factors affecting the economics of the process. **The Soundness of Heavy Forge Ingots.** R. Ferry and C. Roques. The authors present observations, based on practical experience, on the occurrence of cracks, A-segregation, axial porosity, axial segregation, and non-metallic inclusions in large forging ingots of carbon and low-alloy steel. **Control of Conversion Operations by Continuous Measurement of the Temperature of the Bath.** B. Trentini and P. Leroy. A description is given of a method of continuous measurement of bath temperature during converter operation, using a two-colour pyrometer sighted through a tuyere. Typical results

obtained are presented. **A Method of Stopping the Thomas Operation.** J. Galey and N. Denis. A description is given of a method of determining the end-point of the Thomas operation, based on variations of the opacity of the converter flame during dephosphorization. The method also gives information on bath temperature during dephosphorization and at the end of the blow. **An Investigation of the Factors Affecting the Regularity of the Melt in the Thomas Operation.** P. Leroy. IRSID studies of the Thomas process are described. They include investigations into the optimum shape of the converter, the effects of variations in pig iron and lime quality, and control of the process.—G. F.

Fuels and Use of Oxygen for Open-Hearth Furnaces. W. Jackson, R. Wogin, and R. Johnson. (*Iron Coal Trades Rev.*, 1955, **171**, Oct. 14, 889–896; Oct. 21, 951–960). Cold coke oven gas with pitch creosote, and mixed gas with an illuminant, are the main fuels used in firing O.H. furnaces at Appleby-Frodingham Steel Co. The practices adopted and the design of furnaces, ports, and burners are described. The use of oxygen for metallurgical purposes is discussed, and results obtained in lancing the O.H. bath, and refining iron in the ladle and mixer, are given. Finally, oxygen as an aid to combustion with both types of furnace fuel is considered, and details of trials are given.—G. F.

Methods Developed at Armco for Decreasing Scrap Charging Time. W. W. Bergmann. (*J. Met.*, 1955, **7**, May, Section 1, 608–611). O.H. furnace charging time at Armco Steel Corporation's Middletown works has been reduced by concentrated efforts to increase scrap density. The author describes the preparation yard and gives details of home scrap preparation, scrap classification, and uniformity of scrap distribution between furnaces. Maintenance of charging bogies is also considered.—G. F.

The Controlled Charging of Basic Open-Hearth Furnaces. J. McCracken. (*Proc. Staff. Iron Steel Inst.*, 1946–53, **61**, 78–85). The advantages of varying the scrap/pig ratio of the charge in accordance with the variation in hot metal analysis in order to obtain a more consistent metallurgical load on the furnace are discussed. Methods of calculating the carbon equivalent of the carbon, silicon, manganese, and phosphorus in the charge in order to measure this load are described.

A Simple Diagram of Metallurgical Processes in the Basic Open Hearth Furnace. S. Kronmarck. (*Metallurgie*, 1955, **5**, Aug., 250–252). Examples are given of diagrams designed to illustrate oxygen accumulation, dephosphorization, and desulphurization, for training purposes.—L. J. L.

Sulphur Distribution Between Flame and Slag in the Open Hearth Furnace. G. St. Pierre. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1954, 227–234). The author describes a laboratory investigation of sulphur equilibrium between synthetic slag mixtures and various gas atmospheres. Sulphur in the slag is found to be increased by increased slag basicity, higher sulphur concentrations in the flame, and increased temperature. There is an optimum oxygen concentration of the flame, within the range of practical combustion, which results in a minimum sulphur content in the slag.—G. F.

Rare Earths in Steelmaking. G. Cheetham. (*Iron Coal Trades Rev.*, 1955, **171**, July 1, 15–21). The author summarizes existing information relating to additions of rare-earth metals and oxides to stainless, low-carbon, low-alloy, silicon, and other types of steel, giving details of the improved workability and other benefits in each case. The position regarding rare-earth additions is clarified to give a more positive guide to intending users.—G. F.

Activity of Sulphur in Liquid Fe–Ni Alloys. J. A. Cordier and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Aug., 905–907). Using gas equilibrium methods, the authors have found that the chemical behaviour of sulphur in liquid steel is independent of the nickel content, and that sulphur has the same activity and free energy in liquid nickel and Fe–Ni alloys as in liquid iron. Equations are presented defining the thermodynamic properties of sulphur in liquid Fe–Ni alloys, and the effects of other alloying elements on the sulphur reactions in nickel and iron are discussed.—G. F.

System Capacity Required for 3-Phase Arc Furnaces. O. Ramsaur and J. E. Treweek. (*Trans. Amer. Inst. Elect. Eng.*, 1954, **73**, Part IIIB, 1373–1374). In an investigation of the system capacity of a 3-phase arc furnace required to prevent complaints of flicker, it was found that the short-circuit Kva of the 3-phase system should be about 100 times the maximum single-phase swings. A table is given relating rated transformer Kva to this quantity. For several similar furnaces at the same location, this short-circuit Kva must be multiplied by $\sqrt[4]{n}$, where n is the number of such furnaces.

Survey of Stainless Steel Melting Points Up Rapid Progress. R. B. Shaw. (*J. Met.*, 1955, **7**, Dec., 1309–1315). The author reviews modern electric furnace practice for melting stainless steel, discussing separately the melting, oxidation, reduction, and finishing periods. Methods of calculating the oxygen and silicon requirements for the oxidation and reduction periods respectively are described, and graphs are presented relating carbon content to blowing time and chromium content. Finally, hydrogen and oxygen contents of the finished steel are discussed.—G. F.

Construction of " Mock-up " Laboratory Furnaces. P. K. C. Wiggs. (*Iron Steel*, 1955, **28**, Nov., 535–536). Design of laboratory electric furnaces can best be perfected by preliminary experiments with a " mock-up " furnace. " M.I.28 " insulating bricks and " Crurilite " heating elements (Morgan products) are suggested as a useful building kit of parts which can be re-used in further tests.—G. F.

Efficiencies of Electric Furnaces Can Be Increased by Using Higher Voltages. E. L. French. (*J. Met.*, 1955, **7**, Nov., Sect. 1, 1169–1171). The author lists the advantages of using large electric furnaces with higher voltages, and discusses the correct design of large furnaces and the modification of existing equipment to take advantage of this fact.—G. F.

High-alloy Steel Melting in the Basic Arc Furnace. H. C. Templeton. (*Amer. Inst. Min. Met. Eng., Elec. Furn. Steel Conf. Proc.*, 1954, **12**, 122–125). The Lebanon Steel Foundry's basic electric practice for the production of 18/8 stainless steel is outlined. Details of the melting procedure and oxygen lancing are given, and an itemized heat log is presented.—G. F.

Melting Methods in Electric Furnaces. F. Sommer. (*Giesserei*, 1955, **42**, Nov. 10, 629–636). The classical " composition melting " methods in basic electric-arc furnaces including refining, purification and alloying with various elements are described at length. Remelting processes, melting in the Siemens–Martin furnace, double and triple methods and mixed melting methods are dealt with separately. Slag reaction methods are considered, also the degasification of electric furnace steels. Finally, melting and casting *in vacuo* is described.—R. J. W.

Plastic Properties of Söderberg Electrodes. S. Kirchhof. (*Technik*, 1955, **10**, July, 397–403). The dependence of plastic properties of Söderberg electrodes on composition, intergranular thickness of binding agent and its viscosity, was investigated theoretically and experimentally.—J. G. W.

Production of Alloys for Jet Engine Parts by the Electric Ingot Process. (*Indust. Heating*, 1955, **22**, Sept., 1813–1824). A continuous arc melting process for the production of high grade alloy steel ingots is described. A tubular consumable electrode made by continuously forming mild steel strip makes an arc below the surface of a synthetic slag layer. The alloying additions in free-flowing form are automatically fed through the bore of the tubular electrode. The ingot mould is water cooled and melting proceeds without loss of alloying elements.—A. D. H.

Induction Melting. F. S. Leigh. (*Metal Ind.*, 1955, **87**, Dec. 16, 503–506). The author explains the differences arising from the application of a mains frequency supply at 50 cycles instead of high frequency (over 500 cycles). The two main classes of induction melting furnace—the core or channel type and the coreless type—are described. Current penetration and stirring effects are also dealt with.—P. M. C.

Vacuum Melting—A Three Phase Report. J. H. Moore (*Precision Met. Mold.*, 1955, **13**, Oct., 45–48). The general characteristics of the vacuum melting process are reviewed and some results of its application to the melting of alloys for precision casting are given.—D. H.

Out of a Vacuum—Tougher Metals. (*Steel*, 1955, **137**, July 25, 88–90). Two 1000 lb vacuum furnaces built for Utica Drop Forge and Tool Corp., N.Y., are described. A centrifugal mould can be used. Specific application is to high heat-resistant nickel–chrome alloy for jet engine turbine blades.—D. L. C. P.

On the Production of Thomas Slags in Talbot Furnaces. A. Kozina. (*Hutnik*, (Prague), 1955, **5**, (12), 358–360). [In Czech]. The present state of knowledge relating to the production of phosphatic slags is reviewed.—P. F.

Judging Slag Properties from its Appearance, and the Significance of this in Melts Carried out by the Ore-Process in Basic Open-Hearth Furnaces. J. Bečvář. (*Hutník*, (Prague), 1955, **5**, (11), 325–328). [In Czech]. It is shown that in the ore-process, in which 60–70% of the charge is pig iron, a good estimate of the correctness of the refining conditions at all stages of the boil can be obtained from the appearance of slag samples. The appearance indicates slag basicity.—P. F.

On the Relation of the Chemical and Mineralogical Composition of Basic Bessemer Slags to their Solubility. T. Myslivec, A. Walecsek, and P. Kühn. (*Hutnické Listy*, 1955, **10**, (10), 605–609). [In Czech]. The chemical conditions required for the formation of water soluble phosphorus-rich slags as by-products in the steelmaking process in 250-ton tilting open-hearth furnaces are discussed. Low iron oxide contents and a high basicity are desirable, particularly if they are to be used as fertilizers in soils poor in lime.—P. F.

Theoretical Analysis of Recurring Failures in Steelworks: Application to Ingot Mould Life. K. F. Lane. (*Iron Coal Trades Rev.*, 1955, **170**, June 24, 1465–1468). The author explains a mathematical theory for the analysis of recurring failures in components subject to more than one type of failure, giving examples of the application of the method to study of ingot mould life.—G. F.

Casting Pit Practice. G. R. Bashforth. (*Brit. Steelmaker*, 1955, **21**, Oct., 316–320). The author discusses some of the points essential to good casting pit practice. He deals mainly with reaction products and the importance of maintaining good tapholes, ladles, stopper gear, and runner systems, including tundishing. Hot-topping and splash control are also considered.—G. F.

Report of the Semi-killed Steel Subcommittee. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (10), 1963–1969). Balanced steel, semi-killed steel and capped steel are defined. Methods of ensuring the correct relation between carbon and oxygen to produce these steels are outlined.—T. E. D.

Vacuum Melting and Vacuum Processing of Steels. J. H. Moore. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 65–78). Descriptions are given of three types of vacuum melting or processing units; these are the consumable electrode vacuum arc furnace with water-cooled mould anode, the Bochumer–Verein degassing unit, and the vacuum induction furnace. The major reactions occurring in vacuum melting are discussed, and data on the properties of vacuum-melted steels are given.—G. F.

Magnesite Inserts for Fireclay Sockets. S. I. Stupar'. (*Stal'*, 1955, (7), 647–649). [In Russian]. The use of a magnesite–waterglass ramming for introducing magnesite inserts into fireclay sockets for the teeming of high-manganese steels is described.—S. K.

Special Problems in the Continuous Casting of Alloy Steels. R. Chouvel and J. Seloron. (*Centenary Congress of the Société de l'Industrie Minérale*, 1955, Sd. 9, 1–15). An account is given of problems of billet quality, including internal defects and metal properties, as well as of problems of production and productivity. The rolling of continuously cast billets is also considered.—E. C.

One Solution to the Problem of Rupture of the Billet Skin in Continuous Casting. J. Savage. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sd. 8, 1–5). The problem of billet skin rupture is discussed and a description is given of the design and method of operation of the mould evolved by B.I.S.R.A. to overcome skin rupture.—E. C.

Semi-Continuous Casting of Steel in the German Democratic Republic. I. P. Bardin. (*Stal'*, 1955, (5), 472–475). [In Russian]. An account is given of a semi-continuous steel-casting process developed by Baake of Leipzig, the ingots obtained and sections through them being illustrated.—S. K.

Effect of Electric Hot Topping on the Interior of Heavy Ingots. W. Martin and E. Thon. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1765–1774). The interior effect of the old heating methods is reviewed. New tests are described and their results discussed.—A. C.

Electric Hot-Topping of Forging Ingots. E. Johansson and E. Helin. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1755–1765). Tests were carried out on the Swedish process of electric heating to reduce pipe and segregation. The success of small-scale tests led to further work on ingots up to 35 metric tons. Improvement in output was obtained up to 14%. Segregation in the top end was notably reduced and the grain was finer. A saving of 65 DM. per metric ton was obtained.—A. C.

On the Inverted-V Segregated Zone of Large Carbon Steel Ingot. I. Investigation of the Inverted-V Segregated Zone of 20-ton Steel Ingots. III. M. Kawai. (*Tetsu to Hagane*, 1955, **41**, Nov., 1172–1174; Dec., 1233–1236). [In Japanese]. Cf. *ibid.*, 1955, **41**, Aug., 854.

PRODUCTION OF FERRO-ALLOYS

New Method of Casting Silicon Ferro-Alloys. Ya. V. Dashevskiĭ, A. E. Runov, I. S. Kazak, D. D. Zheltov and B. A. Mel'nik. (*Stal'*, 1955, (8), 714–719). [In Russian]. Difficulties associated with the casting of clean and stable ingots from electric-furnace 45% or 75% ferrosilicon are discussed. Experiments are described on the basis of which a new casting method has been developed. The alloy is cast into metal moulds of special design with massive, spray-cooled bottoms. Removable frames are provided for mechanized extraction of the ingots. Among the direct and indirect benefits claimed for the new method are improved metal quality, higher productivity, and reduction in the electricity consumption and costs.—S. K.

Increasing the Stability of High-Grade Ferro-Silicon. T. P. Khazanova and Yu. P. Vasin. (*Stal'*, 1955, (8), 720–727). [In Russian]. An experimental investigation is described of the quantitative effects on the stability of ferrosilicon of admixtures, rate of cooling of the ingot, silicon-content, and the segregation of elements in the ingot. The experiments were carried out with laboratory-produced synthetic alloys and works ferrosilicon. The alloys were subjected to microstructural analysis and to stability tests in various media. It is concluded that stable ferrosilicon can be produced either by using purer raw materials or increasing the rate of cooling of the ingot, the latter measure being the more effective.—S. K.

Some Observations on the Slag–Metal Equilibria Involved in Ferromanganese Production. N. J. Wadia, V. G. Paranjpe and S. Visvanathan. (*Tisco*, 1956, **3**, Jan., 5–18). The experimental procedures employed by the authors are outlined and their results are considered in relation to other relevant work. The influence of total sulphur input on desulphurization and the partition of manganese and sulphur between slag and metal are discussed. The effects of slag composition, basicity, and temperature on the sulphur partition and the significance of the K_{Mn_Si} and K_{Si_S} indices are also dealt with. The article concludes with a consideration of the dependence of carbon content of ferromanganese on the concentrations of silicon and manganese. Correlations of plant data with experimental results are included. (28 references).—L. E. W.

Improving the Structure of High-Speed Steel Obtained from a Casting. E. I. Malinkina. (*Stal'*, 1955, (4), 368–370). [In Russian]. This is a critical discussion of the structure and properties of high-speed steel tools prepared from large castings, with special reference to carbide segregation. 200–400 kg castings of the steel are inferior to small castings or plates, but they can be improved by suitable hot plastic deformation.—S. K.

Chromium–Nickel–Tungsten Steel Type 40 KhNVA. M. F. Alekseenko and G. N. Orekhov. (*Stal'*, 1955, (4), 350–355). [In Russian]. An account is given of an investigation of the possibility of replacing molybdenum by vanadium, tungsten or niobium in type 40 KhNMA (0·36–0·44% C, 0·17–0·37% Si, 0·5–0·8% Mn, 0·6–0·9% Cr, 1·25–1·75% Ni, 0·15–0·25% Mo). Heats of this steel and of steels with the molybdenum replaced respectively by 0·62% W, 0·31% V, 0·25% W–0·16% V, 0·27% Nb were produced and their mechanical properties, hardenability, and liability to temper-brittleness determined. Only tungsten was found satisfactory and its optimal content was 0·8–1·1%. The physical, mechanical, and technological properties of this steel and its machinability by cutting were shown to be equal to those of steel 40 KhNMA.

Some Aspects of the Manufacture of Ferro- and Silico-Manganese in the Electric Furnace. S. Ph. Bacalu. (*J. Four Elect.*, 1955, **64**, Nov.-Dec., 193–195).

FOUNDRY PRACTICE

Silica Dust, Foundries and the Factories Act (1937). L. Webley. (*Found. Trade J.*, 1955, **99**, Oct. 27, 479). Two recent cases which clarify the employers' legal obligations in matters concerning silica dust and Section 47 (i) of the Factories Act (1937) are briefly reviewed.—B. C. W.

The Institute of Foundry Technology in Düsseldorf. W. Patterson. (*Giesserei*, 1956, **43**, Jan. 5, 18–22). The early history and present layout of the building for the Institute

of Foundry Technology which was opened in Oct. 1955 is described. The equipment, the travelling laboratory and the activities of the Institute are described in some detail.—R. J. W.

Structural Anisotropy, Mechanical Behaviour and Standardization of Grey Castings. A. Collaud. (*Giesserei, Technisch-Wissenschaftliche Beihefte*, 1955, May, 767–799). The relationships between the tensile strength and the primary, secondary, and overall structure of grey castings are established and associated with the anisotropy of tensile strength. Similarly the anisotropy of bending strength is investigated in the light of the different structures. Bend testing is described for both long and short rods. The effect of the grey cast structure on the solidification properties, the deformation properties, and the toughness are described. New proposals are made for the standardization of grey castings.—R. J. W.

The Effect of Gases in Pig Irons and Cast Irons. V. Zedník and M. Šícha. (*Slévárenství*, 1956, **4**, (1), Appendix). [In Czech]. By determining the adsorption activity of graphite it was found that the cause of high gas contents in old cast irons is the water adsorption of the graphite and not the direct adsorption of gases from the atmosphere. Grey cast irons were artificially enriched with gas in laboratory and works melting furnaces and the cause of gas bubble formation was thus studied. The critical amount of hydrogen in grey cast irons resulting primarily from steam amounts to 5–10 cm^3 per 100 grams. If the upper limit is approached or exceeded, blow holes form in the castings, while with lower concentrations castings tend to have a "white" surface. The gas-content of pig irons is but little affected by the composition of the blast furnace charge. Vanadium is best removed from pig iron by blowing oxygen-enriched air into the metal in the runner. The gas content of the iron is not thereby increased if the slag is subsequently allowed to take up the oxide phases formed. High silicon contents tend to hinder the vanadium removal. The effect of gases on the metallurgical and mechanical properties of cast irons was studied.—P. F.

How to Choose the Correct Composition of Grey Cast Irons Used for Castings. K. Hanák. (*Slévárenství*, 1956, **4**, (1), 10–16). [In Czech]. The use of graphically represented relationships between variables affecting the choice of chemical composition of cast irons for particular applications is discussed in detail. Nomograms are presented in a manner which, it is claimed, should enable a semi-skilled foundryman to arrive at the correct choice of iron for any given casting.

A Study of Cupola Design and Operating Factors That Influence the Emission Rates From Foundry Cupolas. R. C. Ortgies. (*Trans. Amer. Found. Soc.*, 1955, **63**, 741–744). Data on the emission of dust under various conditions from a particular hot blast cupola stack are presented and the factors influencing such emission are summarized.—B. C. W.

Modern Technology of Cast Iron Melting with Special Reference to Melting in Cupola Furnaces with Water Cooled Linings. M. Czyzewski, C. Podrzucki and Z. Wittek. (*Przeglad Odlewnictwa*, 1955, **5**, (7–8), 195–202; (9), 257–270). [In Polish]. A general review of methods leading to an improvement in the efficiency in cupola melting is given. The following problems are discussed: the use of two or more rows of tuyeres; oxygen enrichment of blast, basic lining and water cooling of lining. (58 references).—V. G.

Researches into the Choice of Materials and Methods of Casting Piston Rings. V. Oliverius. (*Reports of Czechoslovak Foundry Research, Appendix to Slévárenství*, 1955, **3**, (10), 55–62). [In Czech].

Unalloyed Compound Cast Iron Rolls for Rolling Mills. O. Nečas and V. Krhút. (*Slévárenství*, 1955, **3**, (9), 260–265). [In Czech]. Production methods are surveyed, with particular reference to those current at the Klement Gottwald Steelworks in Vitkovice. The method of discontinuous casting, in which casting is interrupted for about a minute after the outer layer has been cast and ferrosilicon is added to the stream of subsequently cast metal for the lower layer), is considered best. If this is used, charcoal iron and roll heat treatment can be dispensed with, without entailing cracking of rolls or unsatisfactory performance.—P. F.

Technological and Metallurgical Requirements for the Manufacture of Gas-tight Cast Iron for Refrigerators. G. Gertz. (*Technik*, 1955, **10**, Sept., 563–567). Factors ensuring gas-tightness of cast iron refrigerator parts, and in the province of engineering design and of metallurgy, are discussed. Reference is made to the suitability of nodular iron.—J. G. W.

Cast Irons in High Temperature Service. R. J. Greene and F. G. Sefing. (*Corrosion*, 1955, **11**, July, 43–49). The oxidation rates of cast irons have been used instead of their growth rates to predict serviceability at elevated temperatures. Data obtained with plain and low-alloyed cast irons and with highly alloyed austenitic cast irons are presented. While unalloyed cast iron is usually only suitable below 900° F, low alloyed irons can be used satisfactorily up to 1100° F and highly alloyed irons, containing up to 30% nickel and 5% each of chromium and silicon, up to and above 1200° F. The last-named can carry loads at high temperatures.—J. F. S.

Fracture of Inoculated Iron Under Biaxial Stresses. I. Cornet and R. C. Grassi. (*J. Appl. Mech.*, 1955, **22**, June, 172–174). Data are presented on the fracture of calcium-silicide inoculated cast iron thin walled tubes, investigated under various ratios of axial to tangential stress, ranging from pure tension to pure compression.—D. H.

The Question of Standardisation of Spheroidal Irons and the Relationship between the Mechanical Properties and Structure of Ductile Cast Iron. C. Pensotti and E. Mortara. (*Schweiz. Arch. Wiss. Techn.*, 1955, **21**, July, 235–237). A discussion of the possibility of a general classification of spheroidal cast iron in terms of structure rather than mechanical properties. The structure of the metal should be sufficiently well known to allow an adequate estimation of the essential properties.

A Comparison of the Microstructure and Mechanical Properties of Nodular Irons Ferritized by Two Stage and Single Stage Annealing Treatments. G. N. J. Gilbert. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1955, **6**, Aug., 11–15). Sub-critical annealing of nodular cast irons gives a sub-boundary structure in the ferrite grains which may result in brittle fracture. This danger can be avoided by a suitable annealing treatment above the critical temperature, e.g. at 900° C.—B. G. B.

Notch Ductile High Strength Nodular Irons. G. A. Sandoz, H. F. Bishop, and W. S. Pellini. (*Trans. Amer. Soc. Metals*, 1955, **48**. Preprint No. 21). Ferritized nodular iron may be reheated to intercritical temperatures (760°–850° C depending on composition) to develop quasi-equilibrium mixtures of untransformed ferrite and austenite. High tensile strength and good notch ductility were produced by water quenching and tempering (at 650° C) the partially austenitized material. Quenched and tempered irons showed greatly superior notch ductility compared with pearlitic grades of equal tensile strength.—E. E. W.

Physical Properties of Spheroidal Cast Irons. F. Khol. (*Slévárenství*, 1955, **3**, (9), 265–269). [In Czech]. Elastic moduli, damping capacity, magnetic and electric constants of grey cast irons and inoculated cast irons are considered and compared, the data being primarily those obtained by the author. The inoculated cast irons are more elastic, they have smaller damping capacities, and their electrical and magnetic properties are close to those of steels. The use of inoculated cast irons is recommended in the production of stators for electrical machines.—P. F.

Working Spheroidal Graphite Iron: Russian Experience. W. G. Cass. (*Iron Steel*, 1955, **28**, June, 319–320). A summary is given of the results of recent Russian research on the forging, stamping, and rolling of spheroidal graphite cast iron. Maximum strength and plasticity is attained between 700° and 1170° C; considerable plastic deformation is withstood between 840° and 1040° C; and forging with a work ratio of 9, and rolling to 50% reduction, may be undertaken.—G. F.

The Influence of Boron and Aluminium Additions on the Graphitization of Whiteheart Malleable Cast Iron. U. Klein and K. Roesch. (*Giesserei*, 1955, **42**, Sept. 15, 507–515). Previous work is reviewed (9 references) in which a refining of the temper graphite distribution was found as a result of adding boron to whiteheart malleable cast iron. The texture and mechanical properties of four series of melts was then investigated:—(*a*) with increasing B-content, (*b*) with increasing Al-content, (*c*) with constant Al-content and increasing B-content, and (*d*) with shortened annealing time. The results obtained were discussed in the light of previously published work.—R. J. W.

Is Oil Quenching Best for Pearlitic. J. E. Kruse. (*Mod. Castings Amer. Foundryman*, 1955, **28**, July, 85–90). The heat-treatment of pearlitic malleable cast iron is considered and results are presented to show the correlation between mechanical properties, machinability, microstructure, and hardness for air-cooled and oil-quenched malleable iron tempered to Brinell hardnesses between 320 and 140. It was found that for the same hardness the oil-quenched and

tempered bars had approximately the same tensile strength as the air-cooled and tempered bars, but had a higher yield strength and a greater elongation.—B. C. W.

Embrittlement, Toughening and Subcritical Thermal Treatment of Malleable Iron. G. E. Kempka. (*Amer. Found. Soc.*, 1955, *Preprint* No. 62). Results are presented to show the effects of phosphorus content and sub-critical thermal treatment on the tensile and impact properties of commercial malleable irons. With increasing phosphorus content the irons become more susceptible to intergranular embrittlement after heating at 440° C. The author suggests that the embrittlement is caused by the segregation of phosphorus to the grain boundaries of the ferrite. Resistance to embrittlement may be achieved by water-quenching from 650° C which also raises the yield and tensile strength without seriously affecting the ductility. It was found that the higher the sub-critical quenching temperature the greater the increase in strength, whereas the maximum elongation was obtained by quenching from 595° C. It is suggested that the increase in strength of the malleable iron after quenching from above 540° C is due to the retention of carbon and nitrogen in solution in the ferrite.—B. C. W.

Effects of Trace Amounts of Tin, Lead, and Antimony on Annealing of Blackheart Malleable Iron. R. C. Shnay, J. E. Wilson, and J. E. Rehder. (*Amer. Found. Soc., Preprint*, No. 63, 1955). The effects of up to 0·011% antimony, 0·029% lead, or 0·046% tin on the annealing of black-heart malleable cast iron were studied by determining the time taken to complete the first stage annealing, and the amount of pearlite remaining after cooling at different rates through the critical range. In the amounts studied neither antimony, lead, nor tin appeared to have any effect on first stage annealing and lead also appeared to have no direct effect on second stage annealing. Antimony appeared to promote graphitization, the effect reaching a peak at about 0·003%, decreasing to a minimum between 0·004 and 0·010%, and increasing as the concentration was further increased. Tin also appeared to have a graphitizing effect which reached a maximum at 0·014%, decreased sharply up to 0·020% and then remained constant.—B. C. W.

Ladle Practice for Acid Steel. G. R. McDaniel and R. S. Haught. (*Amer. Inst. Min. Met. Eng., Elec. Furn. Steel Conf. Proc.*, 1954, **12**, 199–200). The acid electric foundry of Sawbrook Steel Castings Co., Lockland, Ohio, uses both "teapot" and stoppered ladles. Brief details of construction and maintenance are given.—G. F.

Foundry Ladle Practice for Acid Steel. W. Luvisi. (*Amer. Inst. Min. Met. Eng., Elec. Furn. Steel Conf. Proc.*, 1954, **12**, 198–199). Brief details are given of the construction and maintenance of the ladles and stoppers used in the acid electric foundry of Bonney-Floyd Co., Columbus, Ohio.—G. F.

A Metallographic Study of Ruptures in Steel Castings. J. B. Caine. (*Amer. Found. Soc., Preprint*, No. 122, 1955). The metallographic features of the various types of fracture which may occur in steel castings are illustrated and discussed in detail. The types of fracture considered are tensile, transverse, fatigue, heat checks, notch impact, cooling and quenching cracks, and hot tears.—B. C. W.

High Temperature Impact Properties of Cast Steel. C. F. Christopher. (*Amer. Found. Soc., Preprint* No. 123, 1955). The results of notched-bar impact tests carried out between 700° C and 1425° C on eleven carbon and low alloy steels, are presented and discussed in relation to the problem of hot tearing in steel castings. With all steels the energy absorbed in the notched-bar impact test increases above 700° C to a maximum at the temperature where the alloy was fully austenitic, and then decreased, falling off sharply close to the solidus. The results are correlated with the iron–carbon equilibrium diagram which is divided into four regions, (1) a hot tear zone, just below the solidus where the steels have very little ductility, (2) an area where the high carbon steels are brittle because of free cementite in the structure, (3) an area above 1100° C where the steels show the same characteristics and the same impact values, and (4) a region below 1100° C where the steels are tough but the results depend on the composition and temperature of austenite formation. For steels with greater than 1·3% C, the areas (1) and (2) are continuous and the alloy is brittle at all temperatures.—B. C. W.

Ladle Practice. A. P. Guidi. (*Amer. Found. Soc., Preprint* No. 125, 1955). The ladle practice used at the Texas Electric Steel Co., Houston, Texas is briefly described.—B. C. W.

Mutual Action between Steel and Mould material. W. Trommer. (*Giesserei*, 1955, **42**, Aug. 18, 433–440). The causes and remedies for scabbing, burning, sand spots, changes in composition and the presence of reaction gases during the manufacture of steel castings are discussed, with reference to improved economics of finishing. Good casting results can be obtained with green sand moulds by paying attention to details described.—R. J. W.

Contribution to the Testing of Mould Materials. L. Jeníček. (*Slévárenství*, 1955, **3**, (11), 343–352; (12), 380–385). [In Czech]. Experiments, testing-machines, and problems relating to the permeability, strength, and wear-resistance of foundry moulds are discussed.—P. F.

The Use of Plastic Cement Methods for Moulds of Machine Tool Beds. M. Beilhack. (*Giesserei*, 1955, **42**, Sept. 15, 535–537). The manufacture of machine tool beds of weight up to 4200 kg is described. The constitution and properties of the sand mixtures used to make the moulds are given. Different mixtures are used for the moulds, cores, and lids. The method of making the core is described and illustrated. Finally the casting process and the subsequent cleaning and dressing are described.—R. J. W.

Smooth that Alligator Skin! B. Jones. (*Mod. Castings Amer. Foundryman*, 1955, **28**, July, 80–84). Results are presented to show the effects of various sand additives on the surface finish of grey iron castings. The additions studied included western bentonite, sea coal, wood flour, pitch, rosin, corn cereal, and ground coke. The development of a raised honeycomb surface of veined iron with sand containing sea coal, as a result of the coking of this material, is demonstrated in detail.—B. C. W.

It Is Not All Sand. C. A. Sanders and N. Levinsohn. (*Amer. Found. Soc., Preprint* No. 101, 1955). Twenty-two defective castings are illustrated and briefly discussed to show that not all scrap castings are caused by a wrong sand condition.

Contribution to Bentonite Testing. O. Eckart. (*Giesserei*, 1955, **42**, Sept. 1, 462–465). The meaning of the true moisture content of moulding sand is first discussed. A series of experiments is described in which eleven different bentonites are examined. The compression and shearing strengths and the gas permeabilities have been measured for mixtures of these bentonites with sand and different additions of water. Detailed results are tabulated.—R. J. W.

"Wet Clays" Used in Foundry Sands. C. Dias Brosch. (*Bol. Assoc. Brasil Met.*, 1954, **10**, Oct., 363–380). [In Portuguese]. Variations in the method of addition of clay to foundry sands, and the influence of these additions upon mixing times and sand quality, have been studied. In new sands, the clay may be added in powder or plastic form but for reclaimed sands it is best added as a slurry. Flow sheets for the treatment of the raw clay are given. Data relating moisture contents and mixing times to the sand strengths are included and it is shown that the removal of free silica from the clay has a beneficial effect.—P. S.

Theoretical Aspects of Clay Bonding Agents with Reference to *p*H Control of Moulding Sands. M. Itzel. (*Gjuteriet*, 1955, **45**, Sept., 123–128). [In Swedish]. Theories regarding the constitution of clays and the forces acting between clay particles are discussed. It is shown that these adhesive forces can be influenced by changing the ion concentration in the suspension medium. These theories are then applied to moulding sands, examples showing how, by changing the *p*H value, the strength of the sand can be altered.—G. G. K.

The Working Process of the Head of a Sand-Slinger and the Packing of the Mould. A. Ya. Kalashnikova and G. M. Orlov. (*Liteĭnoe Proizvodstvo*, 1955, (4), 14–18). [In Russian]. An account of practical and theoretical investigation on the action of the slinger-head of a sand-slinger and the effect of various factors on mould packing. Equations for sand trajectories are deduced which have been confirmed by stroboscopic viewing of an operating slinger.—S. K.

Ingates. (*Inst. Brit. Found.*, 1955, June 20–24, Paper No. 1136). The hydraulic laws of gating design are outlined and experiments are described which confirm that molten metal at pouring temperatures behaves like a normal fluid. Equations relating rate of flow to the shape and size of the gating system are derived, and the loss coefficients to be used in these equations are determined from practical foundry experiments. The application of the results to foundry practice is discussed with detailed examples to show the use of the equations.—B. C. W.

Moulding Machines. J. B. McIntyre. (*Metal Ind.*, 1955, **87**, Dec. 9, 483–486; Dec. 16, 506–508). The general types of sand moulding machines, both hand and power operated, are described in some detail and several illustrations given. An assessment is made of the main features of each type of machine.—P. M. C.

Contribution to the Theory of the Working of a Sand Slinger. K. Wi. (*Giesserei*, 1955, **42**, Sept. 15, 530–533). This article is a translation from the Russian in which the subject is treated theoretically: it is well illustrated with diagrams. The acceleration of the mould material on the belt of a small conveyor at the entrance of the material into the paddle are first considered. The exit of the sand mixture from the paddle, the forces acting and the motion of the sand particles are then dealt with. Finally the theoretical aspects of paddle profile are discussed.—R. J. W.

Jackets and Weights for Snap Flask Moulding. (*Gjuteriet*, 1955, **45**, Oct., 145–148). [In Swedish]. Details are given of the views held by a Swedish committee regarding the use, construction, and material of jackets for taper moulds. Various types of hinged jackets are dealt with and draft standards are given for pyramid-shaped jackets for standard taper boxes and for a suitable weight intended for general use.—G. G. K.

Stopping Blow-by in Core Boxes. R. L. Olson. (*Amer. Foundryman*, 1955, **27**, May, 101–103). The development of a continuous tongue-and-groove seal which prevents air and sand blowing out of a core box along the parting face, is described, and the applications and advantages of such a seal are briefly discussed.—B. C. W.

Make Plaster Cores in Rubber-Lined Boxes. R. F. Dalton. (*Amer. Foundryman*, 1955, **27**, Apr., 46–49). The procedure for making a rubber-lined core box for plaster moulds using existing equipment and a cold-setting multi-component rubber, is described in detail. Rubber-lined core boxes are easy and economical to make, require no separator for the plaster and may be designed with no draft or even back draft. They have the disadvantage that the rubber may shrink or swell in use.—B. C. W.

Model 288 Core Sand-Blowing Machine. G. S. Taburinskiĭ. (*Liteĭnoe Proizvodstvo*, 1955, (4), 11–14). [In Russian]. The sand-blowing installation described is designed to produce cores weighing up to 60 kg. The installation includes a sand-blowing machine and automatic auxiliary machines.—S. K.

Casting into Permanent Moulds Reduces Production Costs. R. Koula. (*Slévárenství*, 1955, **3**, (11), 341–343). [In Czech]. The conditions favouring the use of permanent rather than sand moulds are discussed. Factors relating to mould design and pouring are considered.—P. F.

Moulding in an Indian Foundry. S. G. Athanikar. (*Inst. Brit. Found.*, 1955, June 20–24, Paper No. 1133). A description is given of the procedures used at the Indian Iron and Steel Co., Kulti for moulding four typical medium to large castings.

Concerning the Manufacture of Thick Iron Castings. (*J. d'inf. tech. Indust. Fonderie*, 1955, June, 5–10). Factors affecting the satisfactory manufacture of castings with a thickness 4 in. or more are discussed. The transfer of heat through the mould and the solidification of metal in the mould are considered.—B. G. B.

Long-Length and Bi-Metal Centrifugal Castings. Controlled Flow of Metal in Permanent Moulds. (*Engineering*, 1955, **180**, July 22, 112–113). Various methods adopted by the Sheepbridge Engineering Group to produce centrifugal castings are described. Bi-metal castings such as aircraft brake drums consisting of a pressed-steel outer shell with a liner of cast iron can be conveniently produced by the methods described.

Modern Methods of Casting. L. W. Pateman and J. R. Rait. (*J. B'ham. Met. Soc.*, 1954, Golden Jubilee Issue, 123–152). The authors review the more important recent advances in the methods of casting metals and alloys with particular reference to the production and testing of steel castings. Precision investment casting is dealt with first, the procedure being described in some detail. The shell moulding process is then described, and followed by an account of centrifugal casting processes. Other recent advances in casting technique such as pressure feeder heads, exothermic moulding and feeding materials, restricted neck feeder heads, and synthetic resin core binders are discussed. 43 references.—P. M. C.

Feeding Steel Castings Produced by the Lost-Wax Process. M. L. Khenkin. (*Liteĭnoe Proizvodstvo*, 1955, (5), 1–7). [In Russian]. This is a detailed discussion based on experimental data of various arrangements for feeding steel castings produced by the lost-wax process. Equations for calculating optimal dimensions of the various parts of the metal-feeding system have been derived, and their use is illustrated by worked examples.—S. K.

Centrifugal Casting Machine Model 550. A. A. Mikhel'son. (*Liteĭnoe Proizvodstvo*, 1955, (4), 18–19). [In Russian]. A centrifugal machine for casting discs and wheels up to 400 and 300 mm in external diameter and thickness, respectively, and with minimal internal diameter of 80 mm is described.

A Jobbing Investment Foundry in South Africa. J. Steele. (*Inst. Brit. Found.*, 1955, June 20–24, Paper No. 1134). The establishment of the first industrial investment casting foundry in South Africa is outlined and some of the methods adopted to overcome difficulties caused by lack of suitable equipment are described. A technique used to produce castings larger than the normal scope of the equipment involves the use of exothermic feeding sleeves on the investment mould.—B. C. W.

The Application of Alloy Steels to Precision Casting. H. J. Meerkamp van Embden. (*Metalen*, 1955, **10**, Sept. 30, 381–386). [In Dutch]. This is a description of a method using lost wax patterns in conjunction with an arc or high frequency furnace for making small special and complicated machine parts of controlled composition exactly fitted to the duty required of them. It is claimed that considerable savings can be expected in materials, equipment, cost, time, etc. because the resultant castings are either ready for use or else need but little finishing.—F. R. H.

Mechanized Equipment for the Production of Shell Moulds. A. I. Korotkov. (*Liteĭnoe Proizvodstvo*, 1955, (5), 8–10). [In Russian]. An account is given of a recently developed installation for the mechanized production of shell moulds, based on free filling by bunker inversion. Best results were obtained with a new resin–sand mixture containing furfurol as the wetting agent.—S. K.

The Use and Function of Chills in Sand Moulds. W. M. Halliday. (*Foundry*, 1955, **83**, Nov., 162, 165, 166, 168). The use of chills in sand moulds is discussed with particular reference to the materials from which they can be made, chill dressings, venting, and chill shapes.—B. C. W.

Use of Strainer Cores and a Draft Standard for Ceramic Strainer Cores. (*Gjuteriet*, 1955, **45**, Nov., 157–164). [In Swedish]. Details are given of the functions, shape, dimensions, and ceramic compositions of such cores and the layout of the gating system. A draft standard is presented for eight round and two rectangular strainer cores having effective areas of from 1·5 to 8 cm².—G. G. K.

Surface and Internal Bubble Control in Poured Investment Plasters. J. N. Trant and R. G. Megaw. (*Trans. Amer. Found. Soc.*, 1955, **63**, 689–692). Methods for ensuring that plaster moulds are free from surface bubbles and yet have small interconnected uniformly dispersed internal bubbles are discussed.—B. C. W.

Glass Cast Moulds for Precision Casting of High Temperature Alloys. (*Indust. Heating*, 1956, **23**, Jan., 140–150). The Corning Glascast process is described. A slurry of 96% silica glass is poured into a plaster mould, dried and fired at 1740°–1920° F. depending on the dry strength required. The process is claimed to be suitable for static, pressure, vacuum, and centrifugal casting of non-ferrous and ferrous alloys.—A. D. H.

Shell Moulding for the Production Engineer. A. Woods. (*J. Inst. Prod. Eng.*, 1956, **35**, Feb., 118–128). An illustrated review of shell moulding techniques and of machinery used in the process is presented.—B. G. B.

Shell Moulding Process and Equipment. J. Sutherland and C. O. Schopp. (*Trans. Amer. Found. Soc.*, 1955, **63**, 355–362). The shell moulding process is briefly reviewed and recent American equipment and installations in this field are described and illustrated.—B. C. W.

Dimensional Tolerances and Surface Structure in Various Shell Cast Metals. R. A. Flinn, W. B. Pierce, F. R. Smith, and P. F. Youngdahl. (*Trans. Amer. Found. Soc.*, 1955, **63**, 143–156). A detailed account is given of the experimental methods used and the results obtained in an investigation into the surface quality, dimensional tolerances, and surface microstructure obtainable in shell moulded castings. The alloys used were a cobalt-base heat-resisting alloy, an alloy steel, a nodular cast iron, a grey cast iron, and a brass.—B. C. W.

Shell Moulding at Lynchburg. R. H. Herrmann. (*Foundry*, 1955, **83**, Oct., 102–115). The facilities and foundry practice at the new shell moulding foundry of the Lynchburg Foundry

Co., Lynchburg, Va. are described in detail. The foundry is a completely integrated, mechanized jobbing shop, making grey and ductile iron castings with a capacity for pouring 10 tons of iron an hour.—B. C. W.

Steelfoundry Facilities of Thos. Firth and John Brown Limited. (*Found. Trade J.*, 1955, **99**, Oct. 6, 389–391). A brief description is given of the Scunthorpe steel foundry of Thos. Firth and John Brown Ltd. and of the foundry practice used therein.—B. C. W.

Defects in Cupola-Melted Iron. J. Bernstein. (*Found. Trade J.*, **99**, Nov. 24, 608–609). [A letter]. Some further observations on the correlation between a characteristic surface defect in grey cast iron and the manganese, silicon, and sulphur contents of the iron are briefly discussed. Micrographs are given to show the excessive concentration of angular MnS inclusions in the vicinity of the holes.

Defects in Cupola-Melted Iron. T. H. Caulfield. (*Found. Trade J.*, 1955, **99**, Nov. 10, 530). [A letter]. An example of gas holes in grey cast iron associated with high manganese contents in the charge and high sulphur contents in the metal is briefly reported. (See previous abstract).—B. C. W.

Defects in Cupola-Melted Iron. A. D. Morgan. (*Found. Trade J.*, 1955, **99**, Oct. 27, 471). [A letter]. A brief discussion is given of some observations on the occurrence of blowholes in cupola-melted iron which were not associated with any of the usual sources of gas porosity. The defects appeared to be connected with the presence of ladle slag containing 36–42% MnO, with high manganese contents in the charge, and with the formation of MnS.—B. C. W.

Effect of Carbon in Foundry Pig Iron Cast Directly from Blast Furnace. W. Oelsen, K. Roesch, and K. Orths. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 641–653). Crucible reactions are used as a basis for discussion. The authors consider the effects of temperature, slag, and dimensions on the speed of carbonization, and indicate the results of cooling cast iron overheated in a siliceous lining. A criterion for the overheating effect is referred to.—A. C.

The Selection of Grey Cast Iron. (*Metal Progress*, 1955, **68**, Aug. 15, 21–36). A comprehensive discussion of the properties of grey cast iron is presented. Among the items considered are: compressive, tensile, and transverse strengths; modulus of elasticity, hardness, fatigue, machinability; the selection of irons for pressure tightness, impact applications, and wear resistance; residual stresses, alloying to modify the as-cast properties, and hardening properties.—B. G. B.

Applications of Mill Casting to Grey and Malleable Iron. F. Naumann. (*Giessereitechn.*, 1955, **1**, Dec., 230–233). This article which deals in general terms with the characteristic features of chill casting, and with grey and malleable iron, was published simultaneously in Czechoslovakia, Poland, Hungary, and Eastern Germany, to initiate closer international co-operation in metallurgical literature.—L. J. L.

The Low Frequency Induction Furnace in Iron and Steel Foundries. W. Von Asten. (*J. Four Elect.*, 1955, **64**, May-June, 109–110; July-Aug., 138–140). The advantages of this form of heating are considered to be: low consumption of energy, long refractory life, little loss of metal, simplicity and ease of manufacture of high quality irons. Examples of the use of this form of heating are given.—B. G. B.

Methods of Testing Cast Irons. J. Foulon. (*Fonderia Ital.*, 1955, **4**, Aug., 365–373). [In Italian]. A detailed account is given of standard tests for cast irons. The author stresses the importance of shape and size of test pieces, methods of casting, pouring and cooling temperatures, and moulding sand quality. The relation between the properties of the test pieces and the finished casting is examined. Considerable technical and statistical data are given in tables.—M. D. J. B.

Hardenability Investigations in Cast Iron. R. Dicke and H. Schiffers. (*Giesserei*, 1955, **42**, Sept. 15, 501–506). The principles of the testing of hardenability are first enumerated. The method of carrying out hardenability tests is described and the composition of the specimens given: pearlitic and ferritic cast irons were used. A comparison is made between the hardness of those specimens heat-treated by flame and those heat-treated in a furnace. The influence of the size of graphite lamellae on the accuracy of the results has been examined. The results of a metallographic investigation are illustrated.—R. J. W.

On the State of Development and Use of Spheroidal Graphite Cast Iron. P. K. Figge. (*Giesserei*, 1955, **42**, Dec. 22, 701–708). The manner in which the spheroidal graphite cast iron production (using the magnesium method) has spread over the world is first reviewed. The definition and classification of these materials and their chemical compositions are then discussed. The melting furnaces and types of raw iron used in Germany are described and followed by a description of the magnesium treatment and the magnesium carrier. The properties of these materials and their heat treatment is given. The standardization in the different countries is compared. Finally, numerous examples are given of the use of spherolitic cast irons.—R. J. W.

Norwegians Apply Automation to Low-Tonnage Shops. L. B. Knight. (*Foundry*, 1955, **83**, Oct., 183–184, 187). Automatic and semi-automatic installations in two Norwegian foundries are briefly described.—B. C. W.

Edgar Allen's in France—Steel Foundry at Hirson. (*Edgar Allen News*, 1955, **34**, Nov., 245–247). The introduction of Edgar Allen's steels to France, and their continued manufacture and casting at Aciéries d'Hirson are described.

Foundry Buildings and Plant. V. Almborg. (*Gjuteriet*, 1955, **45**, Dec., 173–176). [In Swedish]. General hints are given on the layout of foundries operating with cupolas or induction furnaces, sections dealing with furnace siting in relation to metal distribution arrangements, the stock yard, charging facilities, the planning of new buildings and plant foundations.—G. G. K.

Production-Design Teamwork in the Foundry. C. B. Leach, E. L. Windeler and R. F. Sanders. (*S.A.E.J.*, 1955, **63**, May, 40–43) Simplified casting procedures for automotive cylinder blocks have been achieved by both the Chevrolet and Pontiac factories as a result of close collaboration between designers and foundry personnel.—P. M. C.

Mechanized "Dream" Foundry at Oakland Switches Readily from Iron to Steel. (*Western Metals*, 1955, **13**, Mar., 60–62). A brief description is given of the new 5 million dollar foundry recently completed for General Metals Corp., California. The plant has two electric furnaces with a joint capacity of 8 tons per hour, and four cupolas. Versatility of production and utilization of automation are major features of the foundry.—P. M. C.

Five Small Gray Iron Foundries. (*U.S. Dept. Labour, Bureau Labour Statistics Report*, 85, 1955, April, 1–188). A case study of the productivity and factory performance in 5 small American grey iron foundries is presented. The report describes in considerable detail each individual foundry and its manufacturing techniques, labour–management relationship, departmental organization and equipment. All the foundries are independent and carry out jobbing work.

Application of Indirect Chills. C. Locke. (*Trans. Amer. Found. Soc.*, 1955, **63**, 291–292). The use of indirect chills on two production castings is briefly described.—B. C. W.

Application of Chills for Neutralisation of Rib and Boss Hot Spots on Plates. E. T. Myskowski and H. F. Bishop. (*Trans. Amer. Found. Soc.*, 1955, **63**, 295–300). The effect of ribs and bosses on the shrinkage in the parent section was studied with steel plate castings to determine the chill thickness necessary to overcome the hot spots produced at the junction between appendage and plate. A graphical relation between chill thickness and size of ribs or bosses is then given.—B. C. W.

Application of Insufficient Chills. E. C. Troy. (*Trans. Amer. Found. Soc.*, 1955, **63**, 327–329). The results of an experiment to demonstrate that insufficient chills can be used to promote controlled solidification in castings are briefly reported.—B. C. W.

Range of Effectiveness of Chills. V. Paschkis. (*Trans. Amer. Found. Soc.*, 1955, **63**, 13–16). The effect of cast iron disc chills placed at both sides of a steel plate casting on the solidification time is calculated for different chill thicknesses and diameters. To reduce the time involved in the calculations, which were carried out on an analogue computer, the change of physical properties with temperature was neglected so that the results are qualitative rather than quantitative.—B. C. W.

Fluidity of Molten Cast Iron. E. R. Evans. (*Found. Trade J.*, 1955, **99**, Dec. 29, 757–763). Results are presented to show the effects of composition and pouring temperature on the fluidity of cast iron. In general the fluidity was only affected by composition when the solidus temperature was changed. Of the elements studied carbon, phosphorus, and silicon had the greatest effect in increasing the fluidity even when this was measured at a constant interval above the solidification temperature. The composition could be related to fluidity using the formula C.E.F. = C% + ⅓ Si% + ½ P%,

where C.E.F. is the carbon equivalent based on fluidity. However, pouring temperature had the greatest influence on fluidity and it is concluded that most misruns are due to cold metal. So-called "oxidized" cupola metal was found to have the same fluidity as normal metal of the same base composition at the same temperature.—B. C. W.

HEATING FURNACES AND SOAKING PITS

Modern Gas Fired Pusher Furnaces. C. Calmes. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf. 6, 1–15). Results are reported of a survey of all aspects of operation and performance of fourteen gas-fired, pusher-type billet furnaces put into commission since 1950. Seven of these were Morgan furnaces, the others were of the Rust type. The size of the furnaces is related to billet dimensions and optimum sizes are discussed in relation to capacity, handling problems, and economics.—E. C.

Induction-Heating. D. Warburton-Brown. (*Aircraft Prod.*, 1956, **18**, Feb., 42–46). The applications of induction heating, and available types of equipment are discussed. Performance of equipment, its use in case-hardening, metallurgical effects, distortion, and application to brazing and soldering are mentioned.—T. E. D.

Investigations on a Forging Furnace. H. H. Oehler. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1591–1594). The investigations were initiated to improve gas-fired furnace operation. Chamber pressure, rate of heat transfer in relation to flue valve setting, furnace gas condition, and temperature were observed. Useful data with respect to ingot heating time were obtained.—A. C.

Rotary Hearth Furnace for Heating Plate Mill Slabs. F. C. Schoen. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 297–315). The reasons for replacing side-door slab heating furnaces by a rotary hearth furnace at Alan Wood Steel Co., Pennsylvania, are outlined, and a description is given of the furnace and its auxiliaries. Problems encountered in its operation and the general results obtained are discussed.—G. F.

Heating and Annealing Furnaces in Strip Mills. O. Schneider. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1460–1472). The adoption of cold-rolling technique has led to a series of new types of annealing furnaces intended to give the best possible product surface, low heat consumption, and high output. These furnaces cannot generally be run without an atmosphere of protective gas. A continuous flow process has also to be catered for in some cases.—A. C.

On the Heat Efficiency of Large Batch Type Reheating Furnaces. K. Koshiya and H. Shimizu. (*Tetsu to Hagane*, 1955, **41**, Dec., 1247–1251). [In Japanese]. Studies were made of furnaces heating ingots of 6–120 tons weight, and the effects of ingot weight per unit volume of heating chamber, ingot surface/furnace wall area ratio, insulation, ingot size, position of ports, size of checkers, etc. were evaluated.—K. E. J.

Rapid Radiant Heating of Die Blocks. (*Indust. Heating*, 1955, **22**, Nov., 2264–2270). The operation of an automatically programme-controlled radiant heat furnace for heating charges of die blocks weighing up to 20 tons in 3–4 hours is described.—A. D. H.

Scale-Free Heating of Steel. (*Railway Gaz.*, 1956, **104**, Jan. 6, 20–21). The Equiverse system developed by the Incandescent Heat Co. Ltd. for the scale free heating of steel up to 1350° C is described.—D. H.

Electrically-Heated Soaking Pits. G. Schelderup. (*Värm. Bergsmann. Ann.*, 1954, 90–123). [In Norwegian]. After a historical review of soaking pit development, the author gives details of the electrically-heated units at the Christiania Spigerwerk which have now dealt with 1 million tons of steel. Two units have a capacity of 50,000 t/year each. Comparisons are made between the operating costs of electrical versus gas or oil-heated pits, and details are given of measures adopted to reduce the carbon melting loss by adding small quantities of oil to the pit atmospheres. Other points mentioned include improvements to the heating elements, use of controlled atmospheres, even heat distribution, radiation losses during cover removal and typical heating curves.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Modern Furnaces Can Pay Their Way. A. H. Koch. (*Metalworking Production*, 1955, **99** Dec. 30, 2222–2226). The cost of new furnaces has increased considerably during the last few years. There are possibilities for savings with the new models through eliminating of operations subsequent to heat treatment, and by labour saving in the heat treatment plant itself, enabling new furnaces to be amortized in a short period.

Scientific-Technical Session on the Theory, Calculation and Design of Metallurgical Furnaces. I. V. Abramov. (*Stal'*, 1955, (4), 374–375). [In Russian]. The proceedings at a conference held in Moscow in 1954 on metallurgical furnaces are outlined. Theoretical and design aspects, instrumentation, and co-ordination of research were dealt with.—S. K.

The Distortion of Ball-Bearing Steel after Various Heat-Treatments. A. Adachi and Z. Morita. (*Tetsu to Hagane*, 1956, **42**, Jan., 34–39). [In Japanese]. Tests on standard specimens show that oil quenching and martempering are suitable for heat-treatment of ball-bearing steels, and that distortion after (*a*) quenching, (*b*) tempering, and (*c*) sub-zero treatment is generally less than if the treatments are in the order (*a*), (*c*), (*b*). (11 references).—K. E. J.

Temperature Ranges and Construction of Furnaces. C. Albrecht. (*Härterei-Tech. Mitt.*, 1944, **3**, 33–38). The author discusses the construction of furnaces in relation to the temperatures to be used.—R. P.

Accident Prevention and Safety Measures in Heat-Treatment Plants. K. Steinmetz. (*Härterei-Tech. Mitt.*, 1944, **3**, 51–61). The causes of accidents in heat-treatment plants are enumerated and several preventive measures are suggested.—R. P.

Heat Treating at Blairsville is Versatile. (*Steel*, 1955, **137**, Dec. 12, 122–125).

Heat Treating Steel Castings. C. B. Jenni. (*Steel*, 1956, **138**, Jan. 23, 84–88). The benefits from heat treating steel castings and the treatments employed are described. A table specifies temperatures for various types of steel.—D. L. C. P.

Mechanised Heat Treating—The Growing Trend. O. E. Cullen. (*Iron Age*, 1955, **176**, Dec. 1, 99–102). Examples of mechanical heat treating furnaces are given, including their incorporation into automatic production machining lines.

Ultrasonics: Effects on Steel Heat Treatment. H. V. Fairbanks, F. J. Dewez, Jr. (*Iron Age*, 1955, **176**, Dec. 8, 139–142). The purpose of the study described was to determine the resulting grain size, crystal structure, and hardness of ferrite and pearlite of a hypoeutectoid steel, subjected to ultrasonic energy during transformation from the austenite phase to room temperature. It was found the ultrasonic application produced a marked refinement of the grain: the commercial implications of this are considered.—D. L. C. P.

Equilibrium Between Mixtures of CO and CO_2 and Steels. F. Muñoz del Corral. (*Met. Elect.*, 1955, **19**, Apr., 45–49). [In Spanish]. A parameter, y, equal to the ratio of the partial pressures of CO and CO_2 is used to explain the thermodynamic behaviour of such mixtures in the presence of solid iron. For oxidizing or non-oxidizing conditions y has a simple relationship with temperature but for decarburizing–carburizing conditions factors of pressure and carbon activity must be included. Case carburizing, for which values of $y > 40$ are required is also discussed.—P. S.

The Carbon Deposition Reaction over Iron Catalysts. J. Taylor. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 1–6). [This issue].

Practical Experiences Gained in the Works of Auto-Union, at Düsseldorf, Using the "Indugas" Pre-heating Chamber. F. Michel. (*Härterei-Tech. Mitt.*, 1954, **9**, (1), 53–62). The author describes the furnace and pre-heating chamber used, also its mode of action. This is followed by details of the generator used for gas production, employing a nickel catalyst for the methane reaction at 1050° C.—R. P.

The Treatment of Rolling Mill Rolls in the Electric Furnace at the Gorcy Works. (*J. Four. Elect.*, 1955, **64**, Nov.-Dec., 211–214). A short illustrated account of the vertical electric furnaces used for the heat treatment of rolling mill rolls at the Sté Métallurgique de Gorcy, France, is given.—B. G. B.

Further Development of High-Speed Tool Steels Low in Critical Alloying Elements and their Appropriate Heat-Treatment. H. Schrader. (*Härterei-Tech. Mitt.*, 1944, **3**, 189–207). The behaviour of low-alloy high speed steels during heat-treatment is discussed. Hardening, quenching, and annealing are considered. (16 references).—R. P.

Problems in Installing Hardening Plants for the Motor Industry. H. M. Meingast. (*Härterei-Tech. Mitt.*, 1944, **3**, 13–23). The problems met with are discussed, including the question of space, organization, and type of plant. Results are stated.—R. P.

Industrial Demands to be Met by Hardening Plants. H. Knoche. (*Härterei-Tech. Mitt.*, 1944, **3**, 25–31). The author discusses the construction and uses of various types of furnaces. A short description of temperature measurement and control is given.—R. P.

The Tempering of Plain Carbon Steels. E. D. Hyam and J. Nutting. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 22–38) [This issue].

Experiments in the Hardening of High-Speed Tool Steels. A. Kühnert. (*Härterei-Tech. Mitt.*, 1951, **7**, (2), 9–33). A number of variables are tested. A given high-speed steel does not necessarily require the same hardening temperature every time. An increased heating period has the same effect as an increase in hardening temperature. The measurement of induction and of Vickers hardness does not always give results which are a measure of the quality of high-speed steels after hardening.—R. P.

Problems of Quench-Hardening: Aqueous Quenching Baths. H. M. Meingast. (*Härterei-Tech. Mitt.*, 1944, **3**, 123–142). Results of tests are given, using various aqueous quenching baths. With sodium chloride solution, the maximum quenching effect is obtained with a 7·5% concentration. Using sodium hydroxide, the quenching effect increases with concentration but the depth of chill decreases with increase in temperature. The surface hardness obtained with the saline and hydroxide solutions tested is more than that obtained with water.—R. P.

Experiences with Tempering by the Intermediate-Stage Process. O. Schaaber. (*Härterei-Tech. Mitt.*, 1954, **6**, (4), 9–29). The author points out potential pitfalls in using the method. Austenite is quenched at a temperature between that of the pearlite and martensite stage. Transformation has to be carried out at a constant temperature. The influence of hardening temperature, residual austenite, and transformation temperature is discussed. Suitable working conditions are given.—R. P.

FORGING, STAMPING, DRAWING, AND PRESSING

Preventing the Welding of Sheets during Hot Working. M. P. Kesarev. (*Stal'*, 1955, (4), 371–372). [In Russian]. Preliminary painting with potassium dichromate solution has been found to prevent the welding together of sheets of low-carbon rimming steel heated to below Ac_1. 50 g. of 0·2% solution were required for each 510 × 710 mm sheet.—S. K.

So You're Going to Buy a Press? M. D. Verson. (*Iron Age*, 1955, **176**, Dec. 22, 71–73). Points are put forward which should be borne in mind when considering what type of press to buy. Drive, capacity, speed, versatility, lubrication, and special features are considered.—D. L. C. P.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf: Tool Problems in the Extrusion Process. K. Laue. (105–108). The author discusses the extent of mechanical and thermal stresses in extrusion tools, and outlines the steps necessary to increase their efficiency.

Technical Sessions in Paris: The Ugine–Sejournet Process for the Hot Extrusion of Steel. J. Sejournet. The development of glass lubricant in steel extrusion is described, and its effect on metal flow is outlined. The advantages and possibilities of the process, and technical and economic considerations, are discussed. **The Process of Integral Grain Flow Forging and Its New Uses.** M. Bietrix. A brief outline is given of the principles of the "integral grain flow" forging process and of its application to the manufacture of crankshafts, propeller hubs, and shaft flanges.—G. F.

Rolling, Forging Facilities Meet Diversified Needs. R. C. Humphrey. (*Iron Age*, 1955, **176**, Dec. 15, 103–105). A metalworking plant of the Westinghouse Electric Corp. is described, which is used for both development work and speciality production. Forging and hot- and cold-rolling equipment is installed.—D. L. C. P.

Contribution to the Study of the Forgeability of Steels. G. Remy. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (12), 2413–2419). Mechanical tests that can be performed in the laboratory to evaluate the forgeability characteristics of metals, particularly resistance to and capacity for deformation, are examined. Results obtained in this work and from the literature indicate that rate of hot-working influences the hot-working characteristics of the metal.—T. E. D.

Integrated Shop Produces Close Tolerance Upset Forgings with Weight, Cost Savings. V. J. Taylor and L. R. Huizenga. (*Western Metals*, 1954, **12**, Feb., 47–49). A brief description is given of the plant and products of the American Brake Shoe Company's Forge at Azusa, California. A wide variety of close tolerance components are produced by upsetting methods in 2, 3, 4, and 5 inch Ajax machines and 300 and 1300 ton Maxipresses.—P. M. C.

Pilot Plant Links Lab to Production. (*Steel*, 1955, **137**, Dec. 12, 122–123). Special-production and development work are carried out at the Westinghouse Corp. plant at Blairsville. Forging, casting, and heat treating equipment are installed.

Switch to Cold Forming Cuts Production Costs. W. G. Patton. (*Iron Age*, 1956, **176**, Nov. 17, 111–114). Examples are cited of how a small metalworking shop has introduced cold forming methods. A list of advantages and disadvantages is given.—D. L. C. P.

Research into Some Metal-Forming and Shaping Operations. W. Johnson. (*J. Inst. Metals*, 1955–56, **84**, Mar., 165–179). Investigations are described on the drawing and redrawing of cylindrical shells with hemispherical and flat headed punches. The effects of lubrication, drawing speed, flange wrinkling, ironing, tube sinking, the detection and measurement of residual stresses in cold drawn tubes, impact extrusion under drop hammer and coining receive particular mention.

Cold Roll-Forming and Manipulation of Light-Gauge Sections. E. Griffin. (*J. Inst. Metals*, 1955–56, **84**, Mar., 181–197). The advantages of cold forming as a method for producing in large quantity, sections of complicated profile from strip are outlined. The forming process itself is described in detail with accounts of the types of machine used and their capacities, calculation of power requirements and the design and manufacture of roll-forming tools.—B. G. B.

Stretch-Forming. (*Aircraft Prod.*, 1956, **18**, Mar., 106–111). The Hufford Carousel stretch-wrap forming-machine is described and illustrated. This new development permits the additional operations of full-circle rotary-, wrap-, or roll-forming, and also reverse bends, joggling, and stretch-levelling.

Technological Aspects of the Cold Forming of Metal. R. Molle. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 568–582). A comprehensive account of the theory and practice of cold forming is presented. The relation between theory and practice is discussed and examples are given.—B. G. B.

The Deep Drawing and Spinning of Sheet Metal, with Particular Reference to Non-Ferrous Materials. J. A. Grainger. (*J. Inst. Metals*, 1955–56, **84**, Feb., 133–146). Particular attention is devoted to the techniques of Marforming, Hydroforming, and Flowturning. Non-ferrous metal working is mainly considered.—B. G. B.

Inproving Productivity in a Wire Mill. C. C. Tappero. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 139–149; *Wire and Wire Products*, 1955, **30**, Nov., 1379–1382). The author discusses some of the ways in which the productivity of existing wire mills can be improved, giving details of actual examples in industry.—G. F.

Problems of Fine Wire Technology. A. Forstmeyer. (*Wire Prod.*, 1955, **4**, Nov., 15–18). This is an article translated from Feingerätetechnik, 1954, **3**, No. 11, 473–476. The many problems of the manufacture of fine wire, e.g. material and die control, and the uses fine wire is put to, are discussed rather superficially. The need for background research is repeatedly stressed.—J. G. W.

World's Fourth Largest Wire Mill in Brazil. (*Rev. Quim. Industr.*, 1955, **24**, Feb., 34; June, 32). [In Portuguese]. The Companhia Siderurgica Belgo-Mineira has set up a wire mill in the Cidade Industrial (Belo Horizonte) to produce 80,000 to 100,000 tons of wire products per year.—R. S.

Origin of the Invention of Steel Extrusion by Glass Lubrication. J. Sejournet. (*J. Franklin Inst.*, 1956, **261**, Mar., 315–318). A short account of the original work on this technique by the inventor is presented.—B. G. B.

ROLLING-MILL PRACTICE

Proceedings of the All-Union Conference of Rolling-Mill Operators. B. S. Shapiro. (*Stal'*, 1955, (7), 654–656). [In Russian]. The discussions at a rolling-mill conference at Magnitogorsk in April 1955 are reported. Recent and expected progress in the U.S.S.R. is dealt with.—S. K.

Joint Metallurgical Societies' Meeting in Europe, 1955, Technical Sessions in Düsseldorf: Rectifier-Controlled Reversing Rolling Mill Drives. H. Opitz. (49–53). The reasons for the

ever-increasing use of rectifier-controlled reversing rolling-mill drives in Germany are traced, and the system is compared with the Ward–Leonard control. The requirements governing the design and selection of the connection scheme of a rectifier control are outlined, and field installations with armature reversal are described. **Experiences in the Operation of a Rectifier-Controlled Reversing Twin Drive Mill.** W. Moritz. (53–55). The author summarizes his operating experiences on a twin-drive 43 in. blooming mill equipped with rectifier-controlled reversing. Some of the problems encountered are outlined. **Rectifier Drives for Reversing Rolling Mills with Field-Reversal.** H. Anschütz. (56–58). The mode of operation of rectifier drives employing single-set connection with automatic field reversal is described. The construction of the control system and service conditions of the reversing connection are outlined. **Single-Anode Rectifier Technique for Reversing Rolling Mills.** G. Stepken. (58–60). The author outlines the development of the single-anode rectifier control for reversing rolling mills, discussing its advantages over multi-anode rectifiers.—G. F.

Calculation of the Cooling of the Metal during Hot Rolling. A. G. Stukach. (*Stal'*, 1955, (7), 626–629). [In Russian]. As a basis for the estimation of metal/roll pressures in hot rolling a method is developed for calculating metal temperature at every pass. Heat loss from the metal is assumed to be by radiation only, heat input being by deformation. The method was used for calculating metal cooling during the rolling of wire 6·5 mm in dia., of 12 × 2650 mm sheet and a 310 mm Z-beam, giving good agreement with observed temperatures. Some previously proposed methods of calculation are briefly considered.—S. K.

Mechanisation of an Old Type Rolling Mill. E. M. Dolmatov and M. I. Yarovoi. (*Stal'*, 1955, (5), 444–449). [In Russian]. An account is given of the mechanization of labour-consuming operations and the reconstruction of furnaces and other bottle-necks in an old rolling-mill plant by which its productivity has been increased by 28·6%.—S. K.

Position of the Specific-Pressure Maximum with Respect to the Neutral Section. A. I. Tselikov. (*Stal'*, 1955, (7), 649–651). [In Russian]. The distribution of pressure on roll faces during rolling is discussed with special reference to some recently published work on rolling theory.—S. K.

A Study of Failures in Iron Work Rolls. C. F. Peck, Jun., and F. T. Mavis. (*Iron Steel Eng.*, 1955, **32**, Aug., 121–127). This paper presents the second phase of the study of fractured iron work rolls now being carried out at the Carnegie Institute of Technology under the joint sponsorship of the Association of Iron and Steel Engineers and the Roll Manufacturers Institute. Temperature stresses in an actual roll are studied and graphs are given showing the change in the temperature and major temperature stress components as a cold roll is heated up during the first stages of rolling.—M. D. J. B.

Roll Neck Bearing Design—Developments and Trends. R. L. Humphreys. (*Iron Steel Eng.*, 1955, **32**, Sept., 122–126). The paper reviews changes and developments which have taken place at Sparrows Point in the design of open type babbitt, babbitt–bronze grid and fabric bearings.—M. D. J. B.

New Economy in Rolling Mill Bearings. R. G. Walmsley. (*Brit. Steelmaker*, 1956, **22**, Jan., 10–17). The author discusses the properties of laminated fabric bearings, and describes and illustrates a number of examples of their use in industry. The necessary precautions to be taken for main work-roll bearings are listed.—G. F.

Recent Developments in Rolling of Bars and Sections in Japan. M. Yukawa. (*Tetsu to Hagane*, 1955, **41**, July, 732–743). [In Japanese]. An account is given of new equipment installed since 1946 and of improvements made to existing installations, including mention of hot-scarfing equipment, automatic control of reheating furnaces, changes from coal to heavy-oil and high-pressure gas firing, rapid roll re-setting, etc.—K. E. J.

Colorado Fuel and Iron's 3-Stand High Speed Rod Mill. V. W. Johnson. (*Iron Steel Eng.*, 1955, **32**, Oct., 107–116). A description is given of the Colorado Fuel and Iron Corp. Works at Pueblo, Colo. The new 3-stand, high-speed continuous rod mill produces $\frac{7}{32}$ in. rod from $4\frac{3}{8}$ in. billets as there is no mill to roll $2\frac{1}{2}$ billets. Despite this handicap the mill has achieved some very good outputs.—M. D. J. B.

Rolling Thick Sheet to Closer Tolerances. M. M. Gorenshtein, N. I. Petrulevich, and G. V. Tomashevskaya. (*Stal'*, 1955, (8), 753–755). [In Russian]. Organizational and technical measures are described by which closer control of thickness was obtained in the rolling of steel sheet 4–15 mm thick and up to 1650 mm wide.—S. K.

Maximum Utilization and Problems of Wide Strip Rolling and Sheet Finishing Equipment. H. H. Ascough. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 39–61). [This issue].

Ebbw Vale's Modern Look. (*Metal Bull.*, 1956, Mar. 23, 13–16). A short account of the recent modernization of this plant which has been carried out without loss of production is given. A 5-stand tandem cold reduction mill capable of a rolling speed of 5000 ft/min is one of the principal items of new equipment. The possible need for a new continuous strip mill in Great Britain is discussed.—B. G. B.

Thickness Gage That Thinks. (*Steel*, 1955, **137**, Dec. 5, 130–134). An automatic gauge control system on a 5-stand tandem mill for producing cold rolled strip is described. X-Ray thickness gauges control the screwdown on the first stand and the speed of rolls in stand 5, giving a strip thickness tolerance of 0·0001 inch.—D. L. C. P.

Photographic Study of Deformation between the Rolls of a Blooming Mill. J. Stremsdoerfer. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1956, **13**, (1), 177–190). The design of stereoscopic instruments for observing deformation from the side of a blooming mill is described and explained. Results of the observations are interpreted.—T. E. D.

Action of Rolling Lubricants, Particularly Oil Emulsions. J. Billigmann. (*Stahl u. Eisen*, 1955, **75**, Dec. 15, 1691–1701). Present knowledge is reviewed. Experiments are described and results given. Tests were made on a 4-high reversing mill with 88-mm diameter work rolls, rolling up to 80 m/min. The lubricating action of ten different oil emulsions is compared with that of palm oil, undiluted mineral oil, and water. Criteria of lubricating quality, the relationship between laboratory results and practice, corrosion inhibitors, variations in oil composition, grease content of emulsion, change in lubricant properties at high rolling speeds, and emulsion stability are discussed.—A. C.

Ultimate Capacity of a Slabbing Mill. H. G. Jones, D. T. Steer, and P. D. Dickerson. (*Operational Res. Quarterly*, 1956, **7**, Mar., 1–11). Tests carried out at the Steel Co. of Wales to estimate the ceiling capacity of the slabbing mill which controls the total output from the works are described.—B. G. B.

Electrification of J & L's 44 in. Blooming Mill at Aliquippa. G. A. Kaufmann and S. H. Williamson. (*Iron Steel Eng.*, 1955, **32**, Sept., 90–98). A detailed description is given of the changeover from a steam drive to an electric motor drive on a 44-in. blooming mill. The change over took only seven days.—M. D. J. B.

Nylon Rolls Prevent Scratches in Forming Prefinished Strip. K. G. Harms. (*Iron Age*, 1955, **176**, Nov. 3, 104–105). An example of the use of matched pairs of rolls, one nylon, one steel, to form thin gauge strip is given. The method allows pre-laquered strip to be shaped without damage; nylon rolls are less expensive.—D. L. C. P.

Forces and Work in Hot Sawing. G. Wallquist. (*Jernkontorets Ann.*, 1956, **140**, 1, 5–23). [In Swedish]. An account is given of the theory of sawing and the calculation of forces and work involved. Details are given of the influence of factors such as steel composition, transition from the α- to the γ-region, temperature, material dimensions, feed speed, and blade wear on the specific sawing work per mm^3 of stock removal. Comparative Russian and German figures are given for the feed force and the influence of tooth shape on sawing work.—G. G. K.

Problems of Control in Sheet Finishing. M. Berquet. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Se. 2, 1–14). Problems of control in sheet finishing, including tin-plating, are discussed and various control systems are considered for the regulation of speed, tension, cutting, plating current, and re-heating.—E. C.

MACHINERY FOR IRON AND STEEL PLANT

Fastening of Ore Yard Railway Sidings on Concrete. J. Storchs. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1784–1787). Rail anchorage in steelworks is reviewed and particular techniques are discussed.—A. C.

Standard Gauge Traffic in Iron Producing Industry. A. Müller. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1562–1571). The present position of standard gauge rail traffic is reviewed.

Legal aspects are dealt with. Rationalization, labour relationships, and accident prevention are discussed.—A. C.

The New Ymuiden Sheet and Tinplate Works. A. J. Van Wolraven. (*Acier, Stahl, Steel*, 1955, **20**, Sept., 345–351). [In French]. The article describes the structural details of the buildings which house the mills, motor rooms, and stock bays of the new sheet and tinplate works at the Royal Dutch Steelworks.—M. D. J. B.

Blast-furnace Scale Cars for Spain. (*Brit. Engineering*, 1956, **38**, Jan., 252–254). Details are given of three scale cars, of robust design, being built by Head, Wrightson & Co., Ltd., for service in Spain. Each has a capacity of 500 cu ft and a tare weight of 44 tons.—K. E. J.

Simple Torquemeter. S. K. Dean and M. A. Kilburn. (*Engineer*, 1955, **200**, Nov. 11, 686–687). The article describes a simple, robust torquemeter involving the use of a photoelectric cell, developed by B.I.S.R.A. for measuring constant and variable torques in a rotating shaft.—M. D. J. B.

Steel Structure for Rolling Mill. (*Acier, Stahl, Steel*, 1955, **20**, Sept., 357–361). [In French]. The structural details and design features of the new building to house the mills of the Mo i Rana (Norway) steelworks are described. The all-welded structure led to a 20% reduction in weight of steel.—M. D. J. B.

Automatic Control in the Steel Industry. R. W. Holman. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 7–24). The author discusses the state of automatic control applications in the steel industry, considering as examples the control of tandem cold reduction mills, coal by-product processes, electric dust precipitators, and continuous processing lines. The important principles to be observed in the development of "automation" are summarized.—G. F.

Preventive Crane Maintenance. R. S. Bogar. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 193–235). Successful preventive crane maintenance depends firstly on proper engineering of the crane; secondly, on correct erection and testing; thirdly, on the provision of a properly constituted organization for service and maintenance, and finally, on the above phases being supplemented by crane operator training programmes, close co-operation between operating and maintenance of buildings and runways, and general good "housekeeping" throughout the plant. Each of these phases is discussed, with emphasis on maintenance methods.—G. F.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf: Steam-Cooling by Convection Flow and its Application. R. Vonnemann. (100–103). Brief details are given of the design of steam-cooling installations in which circulation occurs by convection only. The advantages of this circulation system over the conventional pump system are discussed.—G. F.

Material-Flow Diagrams in the Rationalisation of Steelworks Transport. W. Hilterhaus. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1480–1494). The construction and use of material-flow diagrams representing the total flow in steelworks are discussed. The detection of bottlenecks and the improvement of works transport are dealt with.—A. C.

Steelworks Electrical Department. Electrical Organization at John Lysaght's of Scunthorpe. (*Elect. Times*, 1955, **128**, Dec. 15, 921–924). An account is given of the scope of the electrical department, particular attention being paid to the organization.—L. D. H.

Transport in Foundries, Aids for the Attaching of Loads. W. Gesell and W. Riege. (*Giesserei*, 1956, **43**, Jan. 19, 47–48). Aids for supporting and slinging loads in the foundry are described and illustrated. Included are various types of adjustable slings, multi-strand rope chains and cable savers.

LUBRICANTS AND LUBRICATION

Theory of Hydrodynamic Lubrication in Parallel Sliding. W. Lewicki. (*Engineer*, 1955, **200**, Dec. 30, 939–941). The author's theory gives a simple explanation of many known phenomena, which were formerly thought to be due to a direct action of molecular forces or the formation of a thermal wedge. The author claims that the new theory is a good approximate solution of the Navier–Stokes dynamical equation.—M. D. J. B.

One Grease for Everything. (*Steel*, 1955, **137**, Dec. 12, 104–106). The use of a lithium base multipurpose grease for all applications in a large pipe mill is described. Advantages are listed.—D. L. C. P.

What Type of Grease for That Application? W. A. Magie and W. C. Bryant. (*Iron Steel Eng.*, 1955, **32**, July, 90–93). This paper brings together certain laboratory tests which indicate that for steel plant use a minimum of four distinct types of grease are needed to obtain best results. Some of these may have to be purchased in two or more grades, as one grade will not serve all seasons.—M. D. J. B.

Crane Lubrication: Some Considerations of the Problems Involved. H. P. Jost. (*Iron Steel*, 1955, **28**, Dec., 661–663). In outlining the problems involved in crane lubrication, the author deals separately with lubrication of crabs, long travel, and crane rails. Methods used in practice are described, and the line and direct feeding systems of long travel lubrication are compared.—G. F.

WELDING AND FLAME-CUTTING

Temperature-Indicating Material Used for Weld Inspection. D. Lichtman. (*Iron Age*, 1955, **176**, Dec. 8, 146–147). The method described was developed to check the welds from an automatic machine at up to 12,000 per hour. It involves a temperature indicating material applied to the back of the work, which is optically scanned after the operation to detect the change which should be given by a good weld.—D. L. C. P.

Propane and Metal Working. S. Smith. (*Canad. Metals*, 1956, **19**, Feb., 20–29). The applications of propane in the metalworking industry are described. These include oxy-propane cutting, welding, brazing, and flame hardening.

On the Weldability of Electric Resistance-Welded Steel Pipe. Y. Shimokawa. (*Sumitomo Metals*, 1955, **7**, Oct., 196–203). [In Japanese]. Investigations on low-carbon rimmed steel pipe show that good welds can be obtained by adjustment of the welding current, with rim-to-rim, core-to-core or rim-to-core welding.—K. E. J.

The Welding of Clad Steels. J. Hinle. (*Welding Metal Fab.*, 1956, **24**, Jan., 11–15; and Feb., 59–62). The different procedures applicable to the welding of different clad steels are discussed, including nickel-, Monel-, Inconel-, or stainless-clad steel, the base being mild or alloy steel. Metal-arc and inert-gas shielded methods are found most suitable and precautions necessary during heat treatment are outlined.—U. E.

Distortion in Welding. Electric Arc Welding. W. T. Amison. (*Welding Metal Fab.*, 1955, **23**, Dec., 475–477; and 1956, **24**, Feb., 63–64). The methods of preventing or counteracting distortion due to rolling, shearing, bending, etc. leaving residual stresses in the metal, or to the action of the electric arc itself, are outlined and discussed.—U. E.

The Weldability and Mechanical Properties of a Series of Mn–Ni–Cr–Mo Steels. C. L. M. Cottrell, B. J. Bradstreet and T. E. M. Jones. (*Brit. Welding J.*, 1956, **3**, Mar., 90–98). The effect of change of composition on the weldability of the steel was assessed by a diagrammatic construction, and compared with diagrams illustrating this effect on the 0·3% proof stress. Tests were then made on a 2-ton cast of a new experimental steel within a chosen range of composition to establish its weldability as shown by the C.T.S. test. It was found that the new steel has an 0·3% proof stress of about 40 tons/sq. in. when normalized as 1-in. thick plate and very good weldability using low hydrogen electrodes, but poor impact properties.

Testing and Proving of Austenitic Welds in 610° C Steam Power Plant. W. Ruttmann and K. Baumann. (*Grosse Schweisstechn., Tagung, Frankfurt*, 1955, 16–26). The properties of a welded pipeline and tube connections to a boiler of 18/8 or 18% Cr, 10% Ni, 2% Mo quality have been investigated. It was found that the use of full austenitic electrodes gives rise to warm cracking. In a number of tables notch impact values are given of austenitic electrodes and weld deposits heated to 600° C and 650° C for 64 weeks.—U. E.

Improved Quality of Structural Steel due to better Fusion Welding Methods. W. Grosse. (*Grosse Schweisstechn., Tagung, Frankfurt*, 1955, 38–45). The stress behaviour and physical properties of open hearth and converter steels are discussed in relation to their suitability for welded construction.—U. E.

Material and Flamecutting. K. Boeckhaus and W. Lenk. (*Grosse Schweisstechn., Tagung, Frankfurt*, 1955, 58–65). The effect of heat on the structure of the adjacent zone of flame cut material has been investigated and the effect of stresses on the property of flame-cut steel sections is discussed. It is shown that high alloy steel can be satisfactorily flame cut without preheating when precautions are being taken.—U. E.

Fusion Pressure Welding of Steel Sections for Concrete. W. Arnds. (*Grosse Schweisstechn., Tagung, Frankfurt*, 1955, 53–57). The fusion pressure welding method applied to steel sections used for reinforcing concrete is discussed.—U. E.

Oxygen Cutting of Mass-Produced Articles. R. Bechtle. (*Grosse Schweisstechn., Tagung, Frankfurt*, 1955, 66–72). Flame cutting of plates, bars, and template of mass-produced articles is discussed.—U. E.

A Review of Literature on the Causes of Porosity in Steel Welds. A. R. Muir. (*Brit. Welding J.*, 1956, **3**, Mar., 98–102). A review of literature shows that gas evolution is thought to be due to solubility changes or chemical reactions. The methods of entry of soluble gases into the weld have been considered and it is thought that entry may be achieved by primary solution in the welding slag and partition between this and the weld metal.—U. E.

Some Aspects of Stainless Alloy Metallurgy and their Application to Welding Problems. M. C. T. Bystram. (*Brit. Welding J.*, 1956, **3**, Feb., 41–46). The influence of stainless alloying elements is discussed on the basis of Schaeffler's diagram and service conditions ranging from − 200° C to + 900° C are taken into consideration.—U. E.

Practical Relationships between Arc Energy, Fillet Size, and Amount of Electrode Used in Metal-Arc Welding. B. J. Bradstreet. (*Brit. Welding J.*, 1956, **3**, Feb., 59–61). The practical relationships between the welding conditions and the resulting weld size in the metal-arc welding of steel are presented in the form of formulae and graphs.—U. E.

Electrode Activation for Inert-Gas-Shielded Metal-Arc Welding. A. Lesnewich. (*Welding J.*, 1955, **34**, Dec., 1167–1178). The effect of addition of extremely dilute, invisible coatings of certain metals and oxides to welding electrodes was investigated. It was found that these stabilize metal transfer and modify deposition rate, penetration, and size and shape of weld bead.—U. E.

Engineering Aspects of Inert-Gas Tungsten-Arc Welding of Piping. H. Thielsch and C. S. Pulliam. (*Welding J.*, 1955, **34**, Dec., 1185–1195). An investigation is reported on the effects of joint design and purging, root-pass cracking, limitations of inspection techniques, advantages of consumable welding insert rings.—U. E.

Crack Arresting by Overlays of Notch-tough Weld Metal. P. P. Puzak and W. S. Pellini. (*Welding J.*, 1955, **34**, Dec., 577s–581s). Crack starter explosion tests were utilized to demonstrate the feasibility of using overlays of notch-tough welds to prevent the initiation and propagation of brittle fracture in otherwise brittle structural mild steels. Whereas fragmentation of the prime plate was obtained in crack-starter tests at 20° and 40° F, similar tests of plates having overlays of notch-tough weld metal showed that brittle fractures do not propagate in overlay regions.—U. E.

Experimental Investigation of Low-Temperature Stress-relieving Methods Applied to Penstocks. M. Okada and M. Watanabe. (*Brit. Welding J.*, 1956, **3**, Mar., 78–83). Results are reported which were obtained from an experimental investigation on the application of low temperature stress relieving to penstocks. Residual stress distribution curves are presented.—U. E.

Some Metallurgical Aspects of Welding. R. B. G. Yeo. (*Engineer Foundryman*, 1956, **21**, Jan., 38–45). The following subjects are dealt with: the iron–carbon diagram, S-curves, internal stress, hard zone cracking of alloy steels, and brittle fracture.—A. D. H.

Welding of Steels in Argon Atmosphere with Consumable Electrodes. E. Sellier. (*Acier, Stahl, Steel*, 1956, **21**, Jan., 11–16). [In French]. A description is given of welding in argon atmosphere. Details are given of the types of steels which can be welded, of the holding equipment, the electrode wire, the argon gas mixture and the methods of preparation of the parts to be welded. Operational techniques and the mechanical characteristics of the welds are also discussed.

Measurement of Shunting Currents in Series Spot Welding 0·036 in. Steel. E. F. Nippes, W. F. Savage, and S. M. Robelotto. (*Welding J.*, 1955, **34**, Dec., 618s–624s). The effect on the short-circuit current of such variables as spot spacing, electrode geometry, backing bar geometry, stock preparation, and electrode force was investigated. The apparatus used to measure the shunting currents is fully explained.—U. E.

Mechanical Properties of Modified Type 347 Weld Metals. R. D. Thomas and L. K. Poole. (*Welding J.*, 1955, **34**, Dec., 583s–595s). Acceptable crack resistance and commercial suitability were demonstrated by a standard type 347 weld deposit, 347 CbTa and 308 ELC type weld deposits. The partially ferritic weld deposits showed greater tendency to embrittle after heat treatments at 1100° and 1300° F than did the fully austenitic type 347 compositions. High notched bar impact values were obtained from the type 308 ELC weld deposit after all heat treating conditions.—U. E.

MACHINING AND MACHINABILITY

Some Fundamental Problems of Machining. E. Bickel. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 537–543). The author discusses the present views on this subject. The definition of the machinability of metals is explained and methods of its measurement are briefly mentioned.—B. G. B.

The Manufacture of Steam Turbine Blading. R. W. Pickard. (*J. Inst. Prod. Eng.*, 1956, **35**, Feb., 100–109). A description is given of the manufacturing techniques used in the fabrication of steam turbine blades. Particular attention is paid to machine tools and production methods.—B. G. B.

Scientific Aspects of Spark Machining. M. Bruma. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 620–626). A short review of the principles of this technique are given. A commercial cutting machine is described. Results obtained during the machining of hard metals are discussed and details of the precision achieved are given.—B. G. B.

Belgian Research on the Machining Properties of Metals. H. Herbiet and L. Cyaplicki. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 544–558). In order to evaluate the complex property of machinability a technique has been devised by a Belgian Committee and is described. An examination has been made of 67 steels which shows the significance and importance of the measurement. The difficulties in the study of machining properties are discussed.—B. G. B.

An Investigation of the Resistance to Wear of Cutting Tools Using Radioactive Isotopes and Irradiation. N. F. Kazakov. (*Izvest. Akad. Nauk S.S.S.R.*, Otdelenie Tekn. Nauk, 1954, (1), 41–53). [In Russian]. An investigation of the mechanism of wear of cutting tools using (neutron) irradiated cutting edges and radiographic study of turnings is described.—V. G.

Contribution to the Analytical Study of the Efficacy of Lubricants Used in the Cutting of Metals. F. Eugène. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 582–594). The author discusses a number of published works on this subject and reviews the present knowledge.—B. G. B.

CLEANING AND PICKLING

HCl Regenerates Waste Pickle Liquor. (*Chem. Eng.*, 1956, **63**, Feb., 132–134). The Ruthner process for recovering sulphuric acid and iron oxide from waste pickle liquor is briefly described, and the development programme whereby the Blaw-Knox Co. and seven U.S. steel producers will test the process is mentioned.—T. E. D.

No Acid in This Pickle Line. (*Steel*, 1955, **137**, Dec. 19, 96–98). The German pickle process described cleans stainless and heat resisting steels without the disadvantages of handling acids. Metal is treated in a fused caustic soda-saltpetre bath and then in a reducing atmosphere furnace.—D. L. C. P.

Chromic Acid–Acetic Anhydride "Explosion." A. E. Dawkins. (*Chem. Indust.*, 1956, Mar. 24, 196). A warning of possible danger is given to users of chromium trioxide–acetic anhydride mixture which may be used in the electrolytic polishing of metals.—E. E. W.

Proper Rinsing Practice Curbs Pinpoint Corrosion. L. J. Brown, S. Spring, W. J. Hennessey. (*Iron Age*, 1955, **176**, Dec. 1, 110–114). An investigation into the problem of pinpoint corrosion on cold reduced steel is reported. Rinse water containing a low concentration of alkali and certain anions, particularly chloride, can give rise to the phenomenon; it can be prevented by using a distilled water rinse.—D. L. C. P.

Degreasing Systems and their Choice. D. J. Fishlock. (*Product Finishing*, 1955, **8**, Aug., 48–56; Sept., 50–55). Solvent, vapour, alkali, electro-alkali, and emulsion methods of cleaning are described and their application to metal degreasing problems are outlined.—A. D. H.

Technical Developments of 1955. N. Hall. (*Metal Finishing*, 1956, **54**, Jan., 43–52). A review of the literature and patents on metal finishing covering 366 references.—A. D. H.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf. Regeneration of Spent Pickle Liquor. W. Fackert. (62–67). The author describes how the problem of regeneration of spent pickle liquor is being dealt with at the Rasselstein works in Germany. The desired objective is outlined and the results obtained to date are discussed.—G. F.

Mechanical Descaling of Rolled Products. O. Peltzer. (68–73). Following a brief outline of the various mechanical methods of descaling rolled products, details are given of a number of types of shot-blasting plant. The different abrasives which may be used are mentioned.—G. F.

Technical Sessions in Paris. Present Status of the Electropolishing of Steel and Special Alloys in Industry. P. Jacquet and R. Mondon. The main industrial applications of the electropolishing process, used for various grades of steel and some special alloys, are reviewed. Attention is given to mechanical applications rather than ornamental uses.—G. F.

Electrolytic Polishing of Stainless-Steel Tubes. N. V. Bogoyavlenskaya and G. N. Bogrets. (*Stal'*, 1955, (5), 449–454). [In Russian]. This article describes comparative experiments on the electrolytic polishing of stainless steel tubes under various conditions and the design and operation of an improved installation for this work. For the experiments pickled tubes were used, without previous degreasing, with various electrolytes. The electrolytes were assessed on the quality of the surface, the current-density range, temperature and duration of the process, the smoothing of the surface and the stability of the electrolyte. A phosphoric-sulphuric acid electrolyte was found to be most suitable. The installation designed can deal with the inner and outer surfaces of tubes of the steel up to 15 mm in diameter and 3·5 m long. It is simpler and more convenient than existing types and can be used for a continuous process.—S. K.

Evaluating Metal Cleaning Efficiency. T. J. Bulat. (*Metal Progress*, 1955, **68**, Dec., 94–95). Radioactive oil and buffing compounds were applied to a standard object and the efficacy of various cleaning methods was measured. Ultrasonic cleaning proved to be most effective.—B. G. B.

On Descaling and Chemical Polishing with Hydrogen Peroxide Solution. II. K. Kawamura. (*Sumitomo Metals*, 1955, **7**, Oct., 204–217). [In Japanese]. The effects of varying the density of solutions and the proportions of H_2O_2, water and acid on the action on a variety of metals are investigated.

The Barrel Grinding and Polishing of Metal Parts. G. Kool. (*Metalen*, 1956, **11**, Jan. 31, 25–34). [In Dutch]. This article deals at length with the treatment of metal castings, machined metal parts, etc. by the operations of grinding, burr removal, polishing, planishing, deoxidation, etc. with the special reference to the drum machines for these purposes obtainable from the N.V. Roto-Finish, Mij. of Delft, Holland.—F. R. H.

PROTECTIVE COATINGS

New Developments in Tests of Coatings and Wrappings. G. E. Burnett and P. W. Lewis. (*J. Amer. Water Works Assoc.*, 1956, **48**, Feb., 100–120). A progress report on the behaviour of a number of coating materials in laboratory and field tests is presented.—B. G. B.

Practical Throwing Power. J. B. Mohler. (*Metal Finishing*, 1956, **54**, Jan., 53–55). The throwing power of commercial plating baths is discussed from a practical aspect and methods are given for the solution of problems of metal distribution.

The Structure of Electrodeposited Metals. R. Weil and H. J. Read. (*Metal Finishing*, 1955, **53**, Nov., 60–65; Dec., 60–64; 1956, **54**, Jan., 56–59). Electrodeposits of nickel, copper, cadmium, zinc, and cobalt were produced from various plating solutions and their structures were studied by electron microscopy. It was found that various structural types of deposit were consistently obtained when the plating conditions were standardized. These structures are supposed to be controlled by the lattice structure of the plated metal and by the quantity of growth-impeding material in the cathode film. The brightness of deposits is considered to depend on the grain size and on the orientation of platelets.—A. D. H.

Corrosion Resistant Properties of Electrolytic Tin Alloy Coatings. (*Usine Nouvelle*, 1955, **11**, Sept. 22, 67). Tin–zinc alloys on steel exhibit the protective properties of zinc coatings and the hard-wearing properties of tin coatings. The alloy usually used is 75% Sn, 25% Zn. The 65% Sn, 35% Ni alloy shows particular resistance to atmospheric sulphur. Some corrosion tests are described, and uses of the alloys are given. Other alloys of interest are Sn–Pb, Sn–Cu, Sn–Cd, Sn–Sb, and Sn–Cu–Zn.—T. E. D.

Trends in "Automation"—Electrolytic Tinning. P. R. Gravenstreter and R. E. Layton. (*Trans. Amer. Inst. Elect. Eng.*, 1954, **73**, Part II, 97–101). A description is given of generator and regulator circuits for the automatic control of the three main types of electrolytic tinning baths—acid, alkali, and halogen. The paper is limited to a discussion of lines having a common generator.—L. D. H.

Containers of Tin Plate and Glass. L. Alquier. (*Mem. Soc. Ing. Civils France*, 1955, **108**, Mar.-Apr., 63–72). A short illustrated description of the manufacture of tinned containers beginning from the preparation of tin plate is given. A brief mention to glass containers is also made.—B. G. B.

Modern Methods of Tinplate Manufacture. B. Keysselitz. (*Metall*, 1955, **9**, June, 490–491). 'Ferrostan,' 'Halogen,' and alkaline baths and installations are briefly described.

Aluminium Coating Increases Oxidation and Corrosion Resistance of Steel. (*Metal Treating*, 1954, **5**, Nov.-Dec., 11). Brief details are given of the General Motors Corporation's patented "Alumicoat" process. The key to the success of the process is said to be the flux bath which consists of sodium and potassium chloride with additions of cryolite and aluminium chloride.—P. M. C.

Alloy Plating. R. T. Gore. (*Product Eng.*, 1955, **26**, Sept., 136–139). Details are given of a number of alloys used for plating, together with the methods of application. The copper–tin (bronze) alloy is discussed in particular, and reference is made to its many good features, and also to the procedure for plating.—E. A. C.

What You Should Know About Clad Steels. H. F. Peters. (*Chem. Eng.*, 1955, **62**, Oct., 234–242). The economy of using clad steel in many industrial processes is discussed. The properties and characteristics of various specifications are mentioned together with details of thickness and sizes available. Behaviour during heat treatment, punching and forming, machining and welding are outlined.

Salt Spray Corrosion of Cadmium. R. H. Wolff. (*Metal Finishing*, 1955, **53**, Apr., 48–55). The results of 20% salt spray tests on cadmium-plated steel are given. A chromate-dip treatment was shown to be beneficial.—A. D. H.

Conveyorized Shell Finishing. E. A. Blount. (*Products Finishing*, 1955, **19**, May, 24–31). Automatic machinery for phosphating, drying and painting 8-in. artillery shells in a U.S. plant are described.—A. D. H.

Plastisols: Versatile Low-Cost Protective Coatings. D. R. Meserve. (*Iron Age*, 1955, **176**, Sept. 8, 77–79). Examples of plastic coating of metalwork for appearance or protection are given. Plastisols are dispersions of finely powdered vinyl resins in plasticizers.—D. L. C. P.

Pre-Treated Metals. (*Indust. Finishing*, 1954, **7**, Dec., 332–355). Mild steel strip already phosphated and enamelled or electro-galvanized and phosphate treated is available in U.S.A. The methods of surface treatment are briefly described and the advantages of this type of material are pointed out.—A. D. H.

Phosphate Coating Retention During Cold Extrusion of Artillery Shells. L. O. Gilbert, S. L. Eisler, J. Doss, and W. D. McHenry. (*Metal Finishing*, 1955, **56**, Apr., 56–58, 61). Previously worked steel slugs were pickled and then phosphated in a bath containing radio-phosphorus. Measurements of radio-activity showed that $\sim$ 89% of the coating remained after the extrusion process.—A. D. H.

Modern Technique of Enamelling on Cast Iron. A. K. Williams. (*Inst. Vitreous Enamellers' Bull.*, 1955, **5**, July, 138–141). Modern enamelling practice for iron castings is described and the influence of foundry practice on enamelling technique is emphasized.—A. D. H.

Pretreated Steel Sheet for Vitreous Enamelling. F. H. Smith. (*Inst. Vitreous Enamellers' Bull.*, 1955, **5**, July, 142–150, 157). The Nitec process which involves degreasing, pickling, electrodeposition of nickel followed by zinc is described. Before enamelling the zinc layer is removed by pickling. The advantages of this material over titanium treated steel and conventional enamelling steel are discussed.—A. D. H.

Mill Additions and their Effects on Titania Opacified Enamels. I. L. S. Golding. (*Inst. Vitreous Enamellers' Bull.*, 1955, **5**, July, 151–157). The theory of the action of conventional additions to wet process enamels is discussed. The reasons for the effect of these additions on the properties of titania opacified enamels are considered.—A. D. H.

Process Control in Vitreous Enamelling. H. W. Clewes. (*Proc. Inst. Vitreous Enamellers*, 1952–53, 1953–54, **11**, 11–20). A method of process control, capable of application to any mass production vitreous enamelling process is described.

Effect of Oxygen Content of Furnace Atmosphere on Adherence of Vitreous Coatings to Iron. A. G. Eubanks and

D. G. Moore. (*J. Amer. Ceram. Soc.*, 1955, **38**, July, 226–230). Further investigations are reported on the mechanism of adherence between enamel ground coats and iron. The effect of the amounts of cobalt oxide in the ground coat and of oxygen in the firing atmosphere were studied.—D. L. C. P.

Modern Porcelain Enamelling System for Stove Parts Utilises Gas Furnaces and Ovens. (*Indust. Heating*, 1955, **22**, Apr., 799–810). The methods and equipment for enamelling gas stove parts in an U.S. works are described. The methods of laboratory control are a feature of the process.—A. D. H.

The Protection of Structural Steel—Painting and Protection of Steel Structures. F. Fancutt. (*Chem. Indust.*, 1955, Nov. 19, 1492–1502). The author comments on the methods available for the protection of steel structures by painting, in the light of experience of British Railways, and discusses in some detail a Code of Practice introduced by the British Transport Commission covering the cleaning and painting of bridges, buildings, and structures.—E. E. W.

The Protection of Structural Steel—Principles of Protective Painting. G. Dechaux. (*Chem. Indust.*, 1955, Nov. 26, 1535–1541). The author discusses briefly the principles of corrosion, the formulation of anticorrosive paints and methods of assessing the efficiencies of various compositions.—E. E. W.

The Protective Function of Paint Coatings on Metals. P. J. Gay. (*Electroplating*, 1955, **8**, Apr., 153—156). The role of coatings in protecting steel is discussed and it is considered that paints normally used are to be regarded as complementary to chemical surface treatments.—A. D. H.

Wash-Primer as a Surface Preparation for Metals and as a General Means of Securing (Paint) Adhesion. H. F. Sarx. (*Werkstoffe Korrosion*, 1955, **6**, July, 331–334). A review.

Past, Present and Future of Electrodeposition. A. W. Wallbank. (*J. B'ham. Met. Soc.*, 1954, Golden Jubilee Issue, 239–242). A brief review of the growth and adaptation to mass production methods of the electroplating industry is presented. The most rapidly expanding branch is the deposition of metals for purposes other than protection or decoration, such as surface hardness, low friction, etc.—P. M. C.

International Review of Metal Finishing. I. S Hallows (Editor). (1954, 171 pp.). Reports are given on the current status of the metal finishing industry in twelve countries, with particular emphasis on recent developments. The following articles are included:

British Trends and Advances in Metal Finishing. S. Wernick. (21–51). **Progress and Developments in Electrodeposition in Belgium since 1945.** R. Corbière. (53–55). **Metal Finishing in Canada.** F. C. Rutherford. (57–63). **Recent Developments in Metal Finishing in Finland.** R. Kyrklund. (65–73). **The Quality Control of Metallic Coatings in France.** P. Morisset. (75–85). **Recent Progress and Future Trends in German Electroplating and Metal Finishing.** R. Springer. (87–107). **Electroplating in Holland.** J. Odekerken. (109–113). **Metal Finishing Trends in India.** T. Banerjee. (115–125). **The Metal Finishing Industry in New Zealand.** S. H. Wilson. (127–135). **Progress in Swedish Metal Finishing.** H. C. Qvarnström. (137–145). **Electrodeposition in Switzerland at the Present Day.** H. Reymond. (147–155). **Electroplating Developments in the United States.** D. G. Foulke. (157–170).—A. D. H.

The Adhesion of Vacuum-Evaporated Metal Films. F. C. Weil. (*Bull. Inst. Met. Finish.*, 1955, **5**, (3), Autumn, 169–176). A general account is given of the techniques of the deposition of metal and alloy films by vacuum evaporation on metals and non-metals. Adhesion of films is discussed.

Temperature Control Systems for Electroplating Vats. D. W. Taylor. (*Metal Finishing J.*, 1955, **1**, Sept., 383–387).

Maintenance Operations in Production Plating. F. G. Brune. (*Products Finishing*, 1955, **19**, May, 32–40). Methods of bath control and plating-shop operation are described.

Instrumentation in the Disposal of Finishing Wastes. A. Linford. (*Electroplating*, 1955, **8**, Nov., 384–388). The legal position concerning the disposal of industrial effluent is briefly reviewed. Methods and instruments for controlling *p*H and rate of flow are discussed.—A. D. H.

Waste Treatment at Douglas Aircraft. (*Plating*, 1955, **42**, Jan., 58–59). A description is given of the plant used for the treatment of plating wastes containing up to 1500 lb cyanide and 2000 lb hexavalent chromium at a combined rate of flow of up to 750 gal/min. Cyanide is oxidized to cyanate with chlorine and the cyanide waste is mixed with reduced chromium solution to precipitate tervalent chromium.—A. D. H.

How does Rust Protection Stand To-Day? H. Hebberling. (*Werkstoffe Korrosion*, 1956, **7**, Jan., 11–13). The author considers that no major changes in good painting practice for steel have occurred since the war; for example, the painting specifications of the German State Railways remain substantially the same. The governing principles are the complete removal of millscale and the use of a genuine red lead priming paint. In fact the old combination of "white lead over red lead" in soap-forming media has not yet been surpassed (he contends) by any more modern painting scheme.

Paints for Structural Steelwork. (*Brit. Iron Steel Res. Assoc.*, 1955, Feb., Third Interim Report Joint Tech. Panel J/P1). The results of an extensive series of tests to ascertain the efficacy of paints for the protection of steelwork are presented. The tests were in four parts. In the first over 100 priming paints were made up in linseed oil, linseed alkyd, and coumarone resin media. A marked superiority of the priming paints with linseed oil medium was found. At least one inhibitive pigment was present in all long lasting paints. In the second series of tests the value of metallic pigments was studied. A marked superiority of aluminium as the pigmenting agent was found. In the third series the use of protective metal coatings and phosphating and flame cleaning steel surfaces was studied. After six years, none of the zinc or aluminium coated specimens had failed by rusting. The best performance of paint on bare steel was on grit blasted unrusted surfaces. Tar and bitumen paints were studied in the last series. Most of the paints gave results that were generally inferior to paints containing drying oils or synthetic resins.—B. G. B.

Maintenance Painting in the Steel Industry. C. Schofield. (*Iron Steel Eng.*, 1955, **32**, Sept., 65–73). After reviewing briefly the various types of paint suitable for steelwork and their characteristics, the author stresses the need of standardization of paint methods in the iron and steel industry, and of equal importance, of standardization of painting procedures and of products in the paint industry.—M. D. J. B.

POWDER METALLURGY

On the Sintering of Mixed Metal Powders of Different Kinds. II. On the Sintering of Mixed Powders of Iron and Nickel. K. Hijikata. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 247–250). [In Japanese]. A homogeneous alloy was formed by calcining a 64 : 34 mixture of iron and nickel nitrates, reducing the oxide powder in hydrogen, compacting at 30 kg/mm² and sintering for 3 hr at 1300° C. The alloy of min. coeff. of expansion was prepared from a metal powder mixture oxidized at 800° for 30 min and reduced at 400° C for 4 hr in hydrogen. Data for other compacts are given, and the mechanism of sintering is explained.—K. E. J.

Powder Metallurgy. J. Cournot, M. Van den Bosch, M. Eudier, R. Girschig, and R. Bernard. (*Métaux Corrosion–Indust.*, 1956, **31**, Feb., 49–103). Five papers from a symposium on powder metallurgy are presented. The introduction is by J. Cournot, the second paper by M. Van den Bosch describes the preparation and use of metal powders, the third by M. Eudier is concerned with the fabrication of parts by sintering, the fourth by R. Girschig describes the manufacture and use of metal carbides, the final paper by R. Barnard discusses magnetic and electrical materials produced by powder metallurgy.—B. G. B.

Sintering Powdered Metals. J. Lomas. (*Machinery Lloyd, European Ed.*, 1955, **27**, Dec. 10, 55). A general elementary review of the processes occurring during sintering.—K. E. J.

Possibilities and Limits of Powder Metallurgy. M. Zeicher. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Nov., 594–605). Examples of the wide application of the powder metallurgical process are presented. These include high temperature alloys, cermets, and porous bearings. (36 references).—B. G. B.

Powder Metallurgy in Japan. T. Kimura and H. H. Hausner. (*Metal Progress*, 1956, **69**, Jan., 61–64). Sintered carbide tools, porous bearings, and electrical contacts are now being produced in large amounts in Japan. Brief details of the extent of production are given.—B. G. B.

Vibratory Compacting of Metal and Ceramic Powders. W. C. Bell, R. O. Dillender, H. R. Lominac, and E. G. Manning. (*J. Amer. Ceram. Soc.*, 1955, **38**, Nov., 396–404). An investigation is reported into the forming of Al_2O_3, Cr–Al_2O_3, and Ni–TiC powders by low frequency vibration, prior to sintering. Properties are similar to pressed specimens, and there are some processing advantages.—D. L. C. P.

Carbide Flame-Plating in Powder Metallurgy. M. A. Teter. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr., 27–28, 68–71). Flame-plating is a process whereby layers of tungsten carbide/cobalt of thickness 0·002–0·010 in. may be applied, by powder deposition, to a wide variety of base metals, giving surfaces of good wear resistance and other properties. Several applications are described, e.g. to core rods, sizing punches, gauges, bearings, and sintered bronze or iron parts.—K. E. J.

The Manufacture of Sheet Metals from Metal Powders. W. D. Jones. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr. 27–28, 60–65). A review is made of possible methods of manufacture of sheet, rod, tubes, and extruded sections from metal powders, and of extractive metallurgical processes yielding powders. For iron, chemical methods of extraction from the ore show promise of producing powder directly. The process of rolling, e.g. copper sheet from powder, and the development of powders of stainless steel, Stellite, Nimonic, etc., for similar purposes is described. Powder spray guns may be used for forming particularly complicated shapes.

Technical Properties of Iron Powder Magnets. E. H. Carman. (*Brit. J. Appl. Phys.*, 1955, **6**, Dec., 426–429). Coercive force, remanence, and maximum energy product of compacts of iron have been measured as functions of density of packing and X-ray particle size. The optimum technical properties are given for an iron prepared by hydrogen reduction of ferric oxide. The presence of a few per cent of oxide does not appreciably affect the quality.—E. E. W.

Investigation of the Mixing of Metallic Powder with the Aid of Tracer Atoms. V. P. Elyutin and A. K. Natanson. (*Zavodskaya Laboratoriya*, 1955, **21**, (7), 820–824). [In Russian]. In powder metallurgy the preparation of homogeneous mixtures of different size-fractions of a given powder or of different powders is important, and a radioactive tracer method has been developed for studying such mixing processes. Activated powders are used, prepared by precipitation on the surface or by precipitation followed by diffusional annealing. The mean square deviation of the radiation from samples taken from different parts of the mixture has been used satisfactorily as a quantitative criterion of the homogeneity of a mechanical mixture of powders. Results obtained with iron powder are presented.—S. K.

Powder Metallurgy versus Other Precision Forming Methods. M. M. Check. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr. 27–28, 56–58). The advantages and limitations of the following processes are discussed: die casting, precision casting, extrusion, manufacture by screw machines, machining, powder metallurgy, stamping, and shell moulding. Examples where powder metallurgical products are superior as to costs, physical properties, etc., are quoted.

Lubrication Practices with Metal Powder Bearings. H. D. Krummell and J. R. Hicks. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr. 27–28, 28–36). Methods for initial impregnation with oil, handling, storage, installation, and lubrication during service are described for porous self-lubricating bearings.—K. E. J.

Friction and Lubrication in Powder Metallurgy. H. H. Hausner and I. Sheinhartz. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr. 27–28, 6–26). Friction in metal powders is analysed. Lubricants used in powder metallurgy are discussed, with their effects on powder flow, density, and friction, and on the compacts. (26 references).—K. E. J.

Semi-Formed Drawing Stock by Powder Metallurgy. R. Steinitz and F. I. Zaleski. (*Proc. Tenth Annual Meeting, Metal Powder Assoc.*, 1954, **1**, Apr. 27–28, 72–76). Preforms, produced from several types of iron powder, were cold drawn to produce cartridge cases of 0·50 in. calibre. The advantages are: elimination of scrap losses, easy control of chemical composition, and moulding of the preforms to the best shape for drawing, no material needing to be moved to the base. The final walls have 100% density.—K. E. J.

PROPERTIES AND TESTS

Errors in Deformation Measurements for Elevated-Temperature Tension Tests. J. M. Thomas and J. F. Carlson. (*Amer. Soc. Test. Mat. Bull.*, 1955, May, 47–51). A number of tests are described in order to show the magnitude of the errors which are possible in this type of test. A method of increased accuracy for calculating the effective length of a test specimen is outlined.—B. G. B.

The Use of the Electrical Extensometer in the Mechanical Testing of Materials. W. Köhler. (*Werkstoffe Korrosion*, 1955, **6**, Oct., 486–495). A detailed description based on many practical examples of the use of the electrical extensometer, employing a steel wire, for the mechanical testing of materials, including vitreous enamelled steel or cast iron.—J. C. H.

On the Stability of Materials under Stress. W. Spath. (*Werkstoffe Korrosion*, 1955, **6**, Oct., 473–478). The author considers the resistance of materials to permanent deformation by continuous stress under conditions of vibration and of creep. He uses a simple mechanical model to point his discussion of the subject, which is wholly theoretical.—J. C. H.

Information on the Process of Metal Failure Obtained by New Microscopic Methods. Z. Kadeřávek. (*Metallurgie*, 1955, **5**, July, 218–226). Examples are given to show that the failure of metals is a complicated process. A series of phenomena occurring prior to actual fracture are determined not only by the yield strength of structural components but by their cohesion. Microscopical examination of microsections provide two-dimensional information. The direct microscopic examination of fractured surfaces provides a third dimension.—L. J. L.

Modern Home-Produced Machines and Instruments for Mechanical Tests. B. A. Avdeev. (*Zavodskaya Laboratoriya*, 1955, **21**, (3), 378–380). [In Russian]. This is a review, with several tables of characteristics, of testing-machines and instruments designed and produced in the U.S.S.R., and some which are to be produced shortly. These include double-action hydraulic pulsating machines up to 800 ± 400 t., horizontal universal machines up to 100 t., hydraulic testing presses up to 1000 t., as well as various fatigue-testing machines.—S. K.

The Instability of Testing Machines. A. H. Chilver. (*Inst. Mech. Eng., Advance Copy*, 1955, Mar. 11). The author demonstrates that the buckling (distortion) of simple compression and tension testing machines may be treated as an elementary problem in elastic stability. It is shown that compression testing machines may be highly unstable if the length of a ball-ended compression specimen is short in relation to the length of the connecting ties. The results of this theory of instability are in good agreement with tests on model and full scale machines. In the case of tension testing machines it is found that for most practical test conditions the specimen length is not a critical factor. (3 references).

Hardness and Plasticity of Metals. J. H. Zaat. (*Metaalinstituut TNO*, Publ. 29, 1955, Jan., 11 pp.). [In Dutch]. The author draws attention to the prevailing uncertainty regarding the meaning of the term "hardness" and endeavours to clarify the position. He goes on to review historically the development of the term and describes the mechanical behaviour of a metal in conjunction with a universal stress-deformation curve. He then discusses the correlation between static hardness and this curve and the resulting practical conclusions to be drawn. It is desirable for hardness measurements to be deduced from an exactly determined universal stress-deformation curve, thus replacing tensile, pressure, torsion, and bending tests.—F. R. H.

The Theory of Plasticity: A Survey of Recent Achievements. W. Prager. (*Inst. Mech. Eng., Advance Copy, James Clayton Lecture*, 1955, Jan. 14). Recent achievements in the theory of plasticity are surveyed with emphasis on applications in mechanical engineering. Kinematic models are presented that indicate the complexities of mechanical behaviour in the plastic range. The fundamental theorems of limit analysis are discussed, and their application to two- and three-dimensional problems is illustrated by examples. Shakedown analysis and limit design are defined. Problems involving large plastic deformations are discussed with special reference to metal forming processes. Applications of plasticity theory to impact testing and blast damage are reviewed. Recent changes in the theory of structural stability in the plastic range are mentioned. (Over 200 references).—P. M. C.

Brittle Fracture and Yielding. A. N. Stroh. (*Phil. Mag.*, 1955, **46**, Sept., 968–972). The stresses around an accumulated group of dislocations may either initiate a crack or operate a Frank–Read source by pulling it from its locking impurities; the latter behaviour is related to the propagation of a Lüders band. This interpretation gives results in accord with experiment, e.g. for ferrite. The model indicates a sharp transition from brittle to ductile behaviour.—K. E. J.

Effect of Temperature on Delayed Yielding of Mild Steel for Short Loading Duration. J. M. Krafft. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 29). An apparatus with a bar loading technique was used to show that the loading stress of a mild steel increases linearly with decreasing logarithm of the delay time before plastic yielding at temperatures between 100° C and − 196° C. Activation energy for delayed yield evaluated at a series of stress levels decreases with increased stress level.—E. E. W.

The Influence of Strain Rate and Temperature on the Ductility of Austenitic Stainless Steel. G. W. Form and W. M. Baldwin, Jun. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 4). The ductility of two austenitic stainless steels was determined in tensile tests over a range of strain rates and a range of temperatures (− 200° C to 400° C). It was found that ductility decreased as strain rate increased, the decrease being greatest at room temperature. The ductility showed a maximum at room temperature at low strain rate, but at high rates it increased slowly and steadily with the test temperature. Magnetic measurements on broken specimens showed that the γ-α transformation cannot account for these observations.

Some Relationships between Endurance Limit and Torsional Properties of Steel. S. T. Ross, R. P. Sernka, and W. E. Jominy. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 10). Comparison of fatigue and torsion tests shows that the maximum endurance limit of tempered low-alloy steels may be estimated from torsional yield strength–hardness data. This relationship is initially linear until a region of high hardness is reached where a condition of instability occurs. Details are given of the types of failure produced.—E. E. W.

Selection of the Type of Notch for Serial Toughness-Testing. B. S. Kasatkin. (*Zavodskaya Laboratoriya*, 1955, **21**, (3), 349–352). [In Russian]. An account is given of an experimental investigation of the effect of notch size and shape on the impact-testing of hot-rolled low-alloy O.H. steel and Bessemer rimming steel. With sharp single-side notches the transition from crystalline to double zone fracture is associated with increasing toughness, and the brittleness of the metal can be reliably evaluated from the change in the appearance of the fracture at the notch with temperature.—S. K.

Comparison between Slow Bend Tests on Notched Test Piece and Charpy V Notched Test Piece. Evaluation of Notch Sensitivity of C-Mn Steel. (*Rev. Soudure*, 1955, **11**, (2), 91–101). [In French]. The object of this paper is to determine which of the various testing techniques adopted in different countries enables the best all-round evaluation to be made of samples of carbon manganese plates 25·4 mm thick. The experimental procedure is described in detail and a complete analysis of results is given. The author concludes that there is little to choose between slow bend tests and Charpy impact tests.—M. D. J. B.

Approximate Calculation of "Notch Toughness-Temperature" Curves in the Region of the Transition Temperature. H. Kornfeld. (*Stahl u. Eisen*, 1955, **75**, Oct. 6, 1324–1330). For heavy plates of conventional structural steels, an improved calculation method gives a better representation of the mean notch toughness in the region of the transition temperature than do existing approximation formulæ. The representation allows the toughness–temperature curve to be derived from results at only two suitably chosen temperatures, with an accuracy sufficient for routing testing. The suggested formulæ are tested and shown to be suitable by comparison with full toughness–temperature curves of six steels.—J. P.

The Calibration of Small Impact-Testing Machines. E. I. Regirer. (*Zavodskaya Laboratoriya*, 1955, **21**, (1), 125–126). [In Russian]. Methods of correcting the readings of small impact testing machines are critically considered.—S. K.

Effect of Heat Treatment on the Strength and Notch Toughness of Hot-working Tool Steels. K. Bungardt, G. Hoch, and O. Mülders. (*Stahl u. Eisen*, 1955, **75**, Aug. 11, 1035–1044). Investigation of the effects of tempering time and temperature on the strength and toughness of hot-working tool steels has shown that short-time tests are only of limited value for assessing the behaviour of such materials in service, since their properties can vary markedly with working time and temperature. It is shown that the Holloman–Jaffe equation for change of properties as a result of diffusion accounts fairly satisfactorily for the interchangeability of time and temperature on mechanical properties. The authors discuss the influence of austempered structure on the stability of temper and on toughness and show that impact values depend on testing temperature. Notch toughness can be improved by multiple tempering.—J. P.

A Criterion for Minimum Scatter in Fatigue Testing. F. A. McClintock. (*J. Appl. Mech.*, 1955, **22**, Sept., 427–431). When a number of fatigue tests are run on specimens with a longitudinal radius of curvature, scatter in the cycles to failure and the position of failure results. If variations in life are due to local inhomogeneities in the specimen a definite relation exists between the scatter in the position and cycles to failure. If the scatter in life significantly exceeds that in position of failure then it is affected by some factors other than local specimen inhomogeneity and such factors can be eliminated by improvement in experimental technique. The usefulness of this criterion is illustrated by its application to crack detection tests on polycrystalline ingot iron.—D. H.

Prediction of Creep-Deflection and Stress Distribution in Beams from Creep in Tension. W. N. Findley and J. J. Poczatek. (*J. Appl. Mech.*, 1955, **22**, June, 165–171). A method of predicting creep in bending from data on creep in tension has been derived and applied to creep of a canvas laminate. Methods of determining creep deflections of beams having non-uniform bending moments are described.—D. H.

Theory of Steady-State Creep Based on Dislocation Climb. J. Weertman. (*J. Appl. Phys.*, 1955, **26**, Oct., 1213–1217). A theory of steady-state creep has been developed using Mott's mechanism of dislocation climb. The resulting equation is valid in the stress range from critical shear stress to a stress about equal to 10^8–10^9 dynes/cm^2. At larger stresses the creep rate increased much more rapidly with stress.—E. E. W.

Improving Casting Quality Through Non-Destructive Testing. F. H. Hohn. (*Amer. Foundryman*, 1955, **27**, May, 96–100). The use of X-radiography in determining the soundness of castings and in improving casting quality is briefly discussed by reference to specific castings.—B. C. W.

Nondestructive Testing of Water-Wheel Generating Unit Mechanical Components. T. C. Stavert. (*Trans. Amer. Inst. Elect. Eng.*, 1954, **73**, Part III B, 1279–1282). Methods used at the South California Edison company are described.

L. D. H.

Non-Destructive Testing of Metals by Gamma Rays. M. Robba. (*Ing. Mecc.*, 1954, **3**, Dec., 25–30; 1955, **4**, Jan., 25–29; Feb., 9–15). [In Italian]. The author gives a comprehensive review in 3 parts of gamma ray radiography techniques for the non-destructive testing of metals. Part I describes the advantages of gamma rays over other testing methods and gives information on common radioactive isotopes. Part II deals with radiographic images, transmission and absorption of radiations, density of blackening, quality, sensibility, contrast, definition, etc. Part III discusses the results which can be obtained by gammagraphic methods and their industrial applications. Finally the health hazards and means of overcoming these are considered. (7 references).

X-Ray Line Broadening from Cold-Worked Iron. R. I. Garrod and J. H. Auld. (*Acta Met.*, 1955, **3**, Mar., 190–198). Measurements of breadths and shapes of X-ray reflections from filings and wire of ingot iron prestressed in tension indicated that lattice distortion is predominantly responsible for the broadening, although particle size also has an effect. The effects of particle size and strain are analysed in terms of the dislocation theory.—A. D. H.

Standard for Checking the Sensitivity of Radiography and Evaluation of Metal Defects on Gamma-Photographs. P. S. Koltunov. (*Avtog. Delo*, 1953, (6), 23–24). [In Russian]. The design and use of standard specimens in testing for defects in boiler shells are considered.—S. K.

Recent Applications of X-rays to the Study of Metals. G. Pomey. (*Métaux–Corrosion–Indust.*, 1955, **30**, July-Aug., 304–311). Among the applications considered are the X-ray microscope, the study of preferred orientation, and the use of Geiger counter techniques for the measurement of stress distribution in rolled sheets.—B. G. B.

The Thermal Conductivity of Metals at Low Temperatures. H. M. Rosenberg. (*Phil. Trans. Roy. Soc.*, 1955, **247**, Mar. 24, 441–497). The thermal conductivity of 32 metals (including iron, cobalt, copper, manganese, and nickel) has been measured from 2 to 40° K and in some cases to 80° K.—B. G. B.

Thermal Conductivity and its Variability with Temperature and Pressure. L. S. Kowalczyk. (*Trans. Amer. Soc. Mech. Eng.*, 1955, **77**, Oct., 1021–1035). The author summarizes the present status of the theory of thermal conductivity and attempts to explain its variability with temperature and

pressure by means of the nature of heat, structure of matter and resistances offered by matter to heat conduction in various physical states. Experimental data are used to illustrate theoretical considerations.—D. H.

Thermal Expansion of Metals. D. Marshall. (*Machine Design*, 1955, **27**, July, 191–193). Tables and charts for quick determination of the thermal expansion of various metals are given.—M. A. K.

The Effect of Quenching on the Thermal Conductivities and Electrical Resistivities of Steels. R. W. Powell. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 6–10). [This issue].

The Effect of Oil Quenching and Tempering on the Thermal Conductivities and Electrical Resistivities of Three Steels. R. W. Powell and R. P. Tye. (*J. Iron Steel Inst.*, 1956, **184**, Sept., 10–17). [This issue].

Metals Used at High Temperatures. J. M. Robertson. (*J. B'ham. Met. Soc.*, 1954, Golden Jubilee Issue, 185–200). A description is given of the mechanical and chemical properties that are important in metals for use in the temperature range 400–950° C. A general classification is then made of steels, and nickel and cobalt base alloys suitable for high temperature use (as in steam and gas turbine plants). Compositions and high temperature properties are given in all cases.—P. M. C.

The Determination of the Coefficient of Diffusion of Hydrogen by an Electrochemical Method. E. A. Aikazyan and A. I. Fedorova. (*Doklady Akad. Nauk S.S.S.R.*, 1952, **86**, (6), 1137–1140). [In Russian]. The coefficient of diffusion of molecular hydrogen was determined by studying the ionization of the latter on polished and platinized platinum rotating disc electrodes in various electrolytes.—V. G.

Hydrogen Occlusion and Equilibrium Hydrogen Pressure in Steel During Electrolytic Charging. F. de Kazinczy. (*Jernkontorets Ann.*, 1955, **139**, (7), 466–480). [In English]. The relation between hydrogen flow through a steel membrane and current density has been investigated and the equilibrium pressure calculated as a function of current density. Using this value the total hydrogen content of the sample after electrolytic charging can be estimated. It is shown that the formation of blisters is determined by the equilibrium pressure, and the pressure required has been calculated for certain mild steels. No correlation was found between hydrogen flow and overvoltage.—G. G. K.

Influence of Grain Boundaries on the Behaviour of Carbon and Nitrogen in α-Iron. G. Lagerberg and Å. Josefsson. (*Acta Met.*, 1955, **3**, May, 236–244). The internal friction of α-iron containing carbon and nitrogen has been measured using samples of different grain size. The finer grained material had lower internal friction and the carbon is probably segregated in grain boundary films. The solubility of carbon increased with smaller grain size. The influence of 0·08% Mn in the sample and of preferred orientation are discussed.

Nitrogen in Iron Anelasticity and Solid Solubility. R. Rawlings and D. Tambini. (*Acta Met.*, 1955, **3**, Mar., 212–213). A linear relationship has been found between the nitrogen content of pure iron and the maximum internal friction at 17° C. The results are compared with those of other workers.

On the Diffusion of Oxygen Through Solid Iron. J. L. Meijering. (*Acta Met.*, 1955, **3**, Mar., 157–162). Metallographic studies of internal oxidation of three iron alloys containing aluminium failed to reveal preferential attack at grain boundaries. The permeability (diffusion coefficient × solubility) of oxygen in iron is calculated from the thickness of the subscale. At 85% of their abs. melting points, the permeabilities of Fe, Cr, Ni and Ag for O_2 are similar in magnitude. Discrepancies in values for solubility of O_2 in γ-iron between several workers are discussed.—A. D. H.

Hydrogen and the Yield Point in Steel. A. Cracknell and N. J. Petch. (*Acta Met.*, 1955, **3**, Mar., 200). A letter in which it is reported that the yield point was removed by cathodic charging with hydrogen. Inhomogeneous stresses arising from the accumulation of hydrogen under high pressures in internal cavities are considered to cause this.

Delayed Failure and Hydrogen Embrittlement in Steel. R. P. Frohmberg, W. J. Barnett, and A. R. Troiano. (*Trans. Amer. Soc. Metals*, 1955, **47**, 892–925). The phenomenon of delayed failure in steel has been correlated with the presence of electrolytically introduced hydrogen. The observed reductions in ductility are a function of both depth of hydrogen penetration and the degree or severity of embrittlement. Ageing with and without load has shown the necessity of exceeding some minimum critical stress in the presence of hydrogen to embrittle steel. Delayed failure occurs in the absence of retained austenite and therefore cannot be attributed to austenite decomposition.—E. E. W.

Relation of Flake Formation in Steel to Hydrogen, Microstructure, and Stress. A. W. Dana, Jun., F. J. Shortsleeve, and A. R. Troiano. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Aug., 895–905). The authors have studied the phenomenon of flake formation in low alloy steels, by introducing controlled amounts of hydrogen into cylindrical specimens followed by a transformation analysis. Both hydrogen and transformation stresses are shown to be necessary for flake formation, and the transformation characteristics of austenite, particularly the nature, distribution, and proportions of the micro-constituents, are of primary importance.—G. F.

Ductile Iron–Aluminium Alloys. E. R. Morgan and V. F. Zackay. (*Metal Progress*, 1955, **68**, Oct., 126–129). Ductile iron aluminium alloys (2 to 14% Al) can be produced by vacuum melting. The alloys have oxidation resistance and high temperature strength equivalent to stainless type steels.

Characteristic Faults of Certain Steels. Marizy. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1955, **12**, (11), 2183–2188). Types of surface defects associated with a range of different types of steels are given. The effects of these defects on the primary products are listed. Causes of defects, and methods of avoiding them are tabulated in detail.—T. E. D.

Studies on Ball-bearing Steels. II. Effect of Some Metallurgical Factors on Life of Ball-bearing Steels. M. Ueno, T. Mitsuhashi, and Y. Nakano. (*Tetsu to Hagane*, 1955, **41**, Oct., 1102–1107). [In Japanese]. Investigations were made on the inner rings on the bearings. Chemical composition had little effect on the life; C content should be low, to avoid segregations and coarse carbide, and Cr content should be controlled to 1·40–1·50%. N content, compressive load, non-metallic inclusions and grain size had no clear effect on the life. Longer life was given by higher hardness after heat-treatment, and a higher % of cementite retained after heat-treatment (max. with 6–8% cementite).—K. E. J.

Stainless Steels. J. Apraig. (*Bol. Min. Indust.*, 1954, **33**, Dec., 661–672). [In Spanish]. A general classification of stainless steels under martensitic, ferritic, austenitic, and valve steel is given and the relevant phase diagrams are illustrated and discussed. The mechanical properties and resistance to oxidation of typical martensite stainless steel (13% Cr or 16% Cr and 2% Ni) and ferritic stainless steel (16% Cr or 27% Cr) are then described.—J. R. P.

Stress Analysis Takes Guesswork Out of Product Performance. W. G. Patton. (*Iron Age*, 1955, **176**, Sept. 15, 131–134). The use of stress analysis of products by Ford Tractor Div. is described. The technique uses stress-sensitive laquer, and strain gauges in the field, and its use on a rotating side-delivery hay rake is described in particular.—D. L. C. P.

A Theory of Fracture and Fatigue. N. F. Mott. (*J. Phys. Soc. Japan*, 1955, **10**, Aug., 650–656). The concept of a piled-up group of dislocations is explained and its significance in relation to ductile and brittle fracture and to fatigue is discussed. It is shown that high stresses may occur at a piled-up dislocation group and these, it is suggested, may induce fracture locally; a large number of small cracks thus brought about can join to produce a ductile or a fatigue fracture.—J. G. W.

The Velocity of Dislocations. J. S. Koehler. (*J. Phys. Soc. Japan*, 1955, **10**, Aug., 669–672). Experimental observations giving the damping experienced by a dislocation and giving the velocity of glide are used to show that the potential energy of a dislocation is in general more than a hundred times the kinetic energy, thereby upsetting the theory for the production of slip bands by Mott and Fisher, Hart, and Pry. It is also shown that twinning requires rapid movement of dislocations whereas slip calls for slow movement. This evidence can be reconciled if it is assumed, with Cottrell and Bilby, that a large twin can be produced by moving a single-twin dislocation through undisturbed material.—J. G. W.

The Migration of Solute Atoms to Dislocation Arrays. B. A. Bilby. (*J. Phys. Soc. Japan*, 1955, **10**, Aug., 673–679). The dislocation theory of strain ageing is applied to the ageing of the dislocation array representing a small angle tilt boundary, and a change in the time law of ageing is predicted.—J. G. W.

The Reversible Bending of Turbine Shafts with Temperature. A. Barker and F. W. Jones. (*Inst. Mech. Eng., Advance Copy,*

1955, May 6). Reversible bending of certain carbon–molybdenum steam turbine shafts is shown to be caused by expansion coefficient differences within the body of the shaft. Such differences are a function of the heat treatment of the shaft and could be caused by faulty normalizing. A defective shaft has been cured by a second normalizing treatment in which the uniformity of austenitizing temperature was improved. The modifications of the expansion characteristics of this steel are associated with different carbide structures. (4 references).—P. M. C.

A General Creep and Recovery Property of Metals. A. J. Kennedy. (*Nature*, 1955, **175**, Apr. 16, 674–676). Creep deformation increases the resistance to further creep while the recovery process reduces this resistance. The author considers the problem as to whether the best material for use under continuous creep conditions is also the best under the discontinuous conditions found in practice.—B. G. B.

The Statistical Theory of Size and Shape Effects in Fatigue. F. A. McClintock. (*J. Appl. Mech.*, 1955, **22**, Sept., 421–426). Fatigue specimens are considered in which the stress amplitude is constant with respect to time but falls off parabolically along the length of the specimen from the point of maximum stress. From assumptions regarding the local variability in the strength of the material, equations are derived relating the scatter in cycles to failure to the scatter in position of failure. The effect of specimen size is determined for these two types of scatter as well as for the average life. It is found that the shape of the distribution function does not seriously affect the relation between scatter in cycles to failure and scatter in position of failure. The size effect is markedly influenced by the shape of the distribution function. A modification is suggested to make the results applicable to tests to determine the endurance limit, where the stress amplitude is a variable.

Static Fatigue of High-Strength Steel. R. H. Raring and J. A. Rinebolt. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 31). Tests were made to determine the effects of melting in air, in vacuum, or in argon atmospheres on the susceptibility to static fatigue of a steel which had been heat treated to high-strength levels, and of baking treatments to effect recovery of plated steels. Resistance to static fatigue failure was determined by applying loads to notched tensile specimens for extended periods of time.—E. E. W.

Creep Rupture Properties of Cold Worked Type 347 Stainless Steel. N. J. Grant, A. G. Bucklin, and W. Rowland. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 2). Static recrystallization studies as well as creep rupture tests of solution-treated and cold-worked niobium stabilized stainless steel confirm that recrystallization occurs up to about 95° C lower during creep rupture than in static tests.—E. E. W.

The Effect of Composition and Structure on the Creep Rupture Properties of 18-8 Stainless Steels. F. C. Monkman, P. E. Price, and N. J. Grant. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 6). Stress-rupture tests were made on twenty-seven 18–8 stainless steels which had been prepared with various amounts of chromium, nickel, and carbon plus nitrogen. Two of these variables were kept constant and the amount of the third was varied. The effects of formation and growth of carbides, ferrite, and sigma during testing were evaluated.—E. E. W.

Hardness-Control with Files. A. N. Polyanskiĭ. (*Zavodskaya Laboratoriya*, 1955, **21**, (3), 355–356). [In Russian]. The design and use of special files for routine hardness testing are described. The technique is particularly suitable for testing rather inaccessible surfaces.—S. K.

New Machine For Micro Hardness Testing. J. D. Dover. (*Commonwealth Eng.*, 1955, **43**, Aug., 15–17). A brief description of a new diamond microhardness testing machine developed in Australia is given.—B. G. B.

Hardenability of Carbo-Nitrided Carbon Steel. R. H. Marshall. (*Metal Progress*, 1955, **68**, Aug. 1, 91–93). An increase in grain size or manganese content increases the hardenability of these steels. Hot-rolled carbon steels with manganese contents between 0·42 and 1·60% were studied and, over this range of manganese, the effect of grain size was greater than manganese content.—B. G. B.

Interpretation of the Relationship Between Vickers Hardness and Load. A. Braun. (*Z. Metallkunde*, 1955, **46**, July, 499–503).

Small-load Hardness and its Elastic and Plastic Components. P. Grodzinski. (*Metall*, 1955, **9**, July, 554–560). The geometry and the basic mechanics of microhardness are discussed. A new definition of hardness is advocated.—J. G. W.

A Study of Antifriction Properties of Chromium Deposits Made Porous by Mechanical Means. D. N. Garkunov and A. A. Polyakov. (*Vestnik Mashinostroeniya*, 1953, **33**, (6), 65–67). [In Russian]. A comparative study of anti-frictional properties of ordinary porous chromium and chromium made porous by mechanical means showed the latter to be superior under conditions of friction against grey iron and also in regard to the friction coefficient.—V. G.

Cast Copper Anti-Frictional Steels. A. A. Lunev. (*Liteĭnoe Proizvodstvo*, 1955, (5), 15–18). [In Russian]. The wear-resisting and related properties of copper-containing steels and the effects of other alloying elements are considered. Good resistance to dry wear was obtained on impregnating copper steels with tin and bismuth. Microstructures of several copper–aluminium steels are illustrated.—S. K.

Wear Tests. H. W. Hahnemann. (*Z.V.d.I.*, 1955, **97**, Sept. 1, 888–890). Investigations of the abrasive wear of metallic and non-metallic materials by minerals and fluids are summarized. The results of laboratory tests were satisfactorily correlated with service performance.—J. G. W.

Metal Transfer and the Wear Process. M. Kerridge. (*Proc. Phys. Soc.*, 1955, **B**, **68**, July 1, 400–407). Experiments with a radioactive, annealed steel pin, rubbing against a hardened steel ring, show that wear proceeds in several steps: (i) removal of material by transfer, (ii) building-up of this material in a hard form on the other test-piece, (ii) oxidation of the layer, and (iv) removal of oxide to form wear débris.—K. E. J.

The New Magnetic Sheet with Orientated Crystals. G. H. Perrin. (*Usine Nouvelle*, 1955, **11**, Dec. 8, 63–65). Transformer sheet with orientated crystals contains less silicon than conventional transformer sheet. It is produced by hot-rolling followed by repeated cold-rolling and reheating until the required thickness, about 0·35 mm, is obtained. Finally, it is heated in pure, dry H_2 at 1100°–1200° C. The behaviour of this sheet in alternating current is compared with that of conventional sheet.—T. E. D.

The Thermal Effects Associated with the Magnetization of High-Coercivity Materials. L. F. Bates and A. W. Simpson. (*Proc. Phys. Soc.*, **B**, 1955, **68**, Nov. 1, 849–858). To overcome electrical difficulties encountered with small specimens, a special arrangement, consisting of a thermocouple of tightly-twisted fine wire coupled with a sensitive galvanometer circuit, was used to investigate heat changes accompanying magnetization in high-coercivity materials, over a field range of 4000 oersteds. Magnetic and thermal properties are given for ferrous alloys of the Alnico, Alni, and Alcomax series, and 'Gecalloy' and Co–Pt alloy. Results are in agreement with the Stoner–Rhodes magnetization theory.—K. E. J.

Preparation of Thin Magnetic Films and Their Properties. M. S. Blois, jun. (*J. Appl. Phys.*, 1955, **26**, Aug., 975–980). Vacuum evaporation techniques are described for the preparation of single thin layers and laminated structures of ferromagnetic alloys.—E. E. W.

On the Origin of Magnetic Anisotropy Induced by Magnetic Annealing. S. Chikazumi and T. Oomura. (*J. Phys. Soc. Japan*, 1955, **10**, Oct., 842–849). The magnetic anisotropy of iron–nickel alloys, induced by magnetic annealing, was measured as a function of composition and analysed. A consistent explanation in terms of the dipole–dipole interaction in a directionally ordered arrangement of atoms was successfully attempted.—J. G. W.

Relationship Between Practical Working Techniques and Fundamental Engineering Principles. M. Panetti. (*Ing. Mecc.*, 1955, **4**, Nov., 5–9). [In Italian]. The author discusses the mechanics of large masses for power accumulation, as in the case of flywheels of reversible and continuous rolling mills, and examines the phenomenon of metal plasticity in the mechanical working and machining of metals. The fundamental hypotheses governing the point at which plastic flow can be considered to commence are discussed as well as the values of maximum elongation, maximum tangential stresses and maximum work of plastic deformation. A mathematical solution to the problem of determining the starting point of metal flow is envisaged. The author describes the modern trend of using the properties of plasticity in shaping metals (e.g. extrusion) in place of machining.—M. D. J. B.

Hypo-elasticity and Plasticity. A. E. Green. (*Proc. Roy. Soc.*, **A**, 1956, **234**, Jan. 24, 46–59). A general theory of work-hardening in compressible plastic materials is developed as

a special case of Truesdell's theory of hypo-elasticity, and several applications are discussed. (16 references).—K. E. J.

Elevated Temperature Properties of Carbon Steels. W. F. Simmons and H. C. Cross. (*Amer. Soc. Test. Mat. Spec. Tech. Pub.*, 1955, No. 180, Sept.). The report is a graphical summary of the elevated-temperature strength data for carbon steels. It includes summary curves for tensile strength; 0·2% offset yield strength; % elongation and reduction of area; stresses for rupture in 100, 1000, 10,000, and 100,000 h, and stresses for creep rates of 1% in 10,000 and 100,000 h.—B. G. B.

Materials for High Temperature Steam. H. Tietz. (*Tek. Tidskr.*, 1955, **85**, Dec. 6, 1011–1013). [In Swedish]. A brief review of problems attendant upon the use of alloyed tube steels for temperatures above 450° C discusses economic stress levels, German methods of calculating creep-fracture limits, impact resistance, reasons for intercrystalline and stress corrosion in austenitic steels, thermal stresses, and suitable methods of welding austenitic material.—G. G. K.

Development of High Quality Heat Resistant Materials. K. Bungardt. (*Stahl u. Eisen*, 1955, **75**, Oct. 20, 1383–1389). The author describes austenitic chrome–nickel steels, chrome–cobalt–nickel–iron alloys, and nickel–cobalt alloys, as the principal materials with useful high-temperature strength properties, and he gives relevant numerical data. He evaluates these materials in terms of their required working life, and discusses the possibilities of further development with particular regard to metal–ceramic combinations.—A. C.

Thermal Stability and Heat-Resistant Materials. S. Arwidson. (*Värm. Bergsmann. Ann.*, 1954, 61–89). [In Swedish]. After defining creep and the nature of creep curves, the author describes equipment used for creep tests and establishing dynamic hardness. Methods for evaluating creep resistance and the influence of C, Cr, Mn, W thereon are discussed together with typical heat-resistant alloy steels.—G. G. K.

Comparison of the Physical Properties of Low- and High-Nickel Steels. R. Cazaud. (*Rev. Mét.*, 1955, **52**, July, 579–585). Tests were carried out on a number of heat-treated nickel steels containing less than 1·6% Ni to determine their physical properties. In general, for a given tensile strength, low nickel steels have equal if not better endurance strengths than higher nickel steels. The resistance to fatigue tests on notched specimens is also similar.—G. E. D.

The Properties of Steels 15Kh and 12KhN2A Containing Boron. M. V. Pridantsev, G. L. Livshits, and D. A. Kal'ner. (*Stal'*, 1955, (8), 734–739). [In Russian]. The properties of industrial heats of two boron-containing steels were studied together with those of the corresponding steels without boron. It was found that the addition of boron with preliminary or simultaneous deoxidation of the steels with titanium or aluminium considerably increased their hardenability and improved their plastic properties. Boron increased the stability of austenite in the lower transformation range and improved the microstructure. Suitable compositions and properties of boron-containing steels are suggested.—S. K.

Development and Present Position of Non-Magnetic Steels. W. Grass. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1558–1562). A review is given of progress in Germany and elsewhere during the last 25 years. The chemical composition, yield point, tensile strength, elongation, notch impact strength, hardness, austenite stability, magnetic permeability, electrical resistance, machinability, and general application of non-magnetic steels are all dealt with.—A. C.

Nickel Conservation with High-Manganese Stainless Steels. F. P. Huddle. (*Metal Progress*, 1955, **68**, Dec., 100–103). The use of high-manganese stainless alloys could replace between half and two-thirds of the nickel-bearing stainless steels. The price differential favours the selection of the manganese steels.—B. G. B.

Low-Alloy Heat-Treatable Steels. H. Briefs. (*Härterei-Tech. Mitt.*, 1944, **3**, 209–218). The heat-treatment, structure, and properties of these steels are discussed.—R. P.

Guides for the Selection of Appropriate High-Speed Steels. W. Haufe. (*Härterei-Tech. Mitt.*, 1952, **7**, (3), 29–51). After discussing various tool steels and their uses, their " useful life " is considered. Performance and economic factors are discussed. (22 references).—R. P.

Alloy and Special Steels of the Avesta Steelworks. (*Acciaio Inossid.*, 1955, **22**, Sept.-Oct., 174–181). [In Italian]. This article describes the various alloy and special steels developed in the last few years at the Avesta Steelworks, which because of the high cost of the alloying elements have not come on to the market on a large scale.—M. D. J. B.

Modern Research Methods in the Alloy Steel Industry. H. Krainer. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Se. 4, 1–10). A survey is made of modern laboratory techniques used in studying the properties of alloy steels. Applications in industrial control are described.

METALLOGRAPHY

Neutron-Capture Gamma-Ray Spectra of V, Co, Ti, Fe, Cr, Au, Mn and I. M. Reier. (*Phys. Rev.*, 1955, **100**, Dec. 1, 1302–1308). The data from an experiment (using NaI crystals at about 100 Kev to 2·5 Mev) are compared, where possible, with results of previous experiments and existing energy level schemes.—E. E. W.

The Methods of Metal Deformation. L. Habraken and T. Greday. (*Rev. Univ. Min.*, 1956, 9th series, **12**, Feb., 38–55). A general review is made of the present knowledge of metal deformation as obtained primarily from X-ray and microscopical studies. The paper is in two parts; the first considers the various types of dislocation and the second their interpretation by the dislocation theory. (50 references).—B. G. B.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Liège: Structural Hardening in Low Alloyed Steels for Creep at High Temperature. L. Habraken and A. de la Motte. The authors have studied structural hardening in chrome–molybdenum steels, some containing vanadium and tungsten, and have identified the precipitates causing the hardening. The vanadium and tungsten additions do not stabilise the original structure and creep properties depend on the transformations taking place.

Technical Sessions in Paris: Evolution of the Structure of Supersaturated Solid Solutions during the Age Hardening Process. M. Guinier. A summary is given of recent French research on the mechanism of the age-hardening and precipitation phenomena in oversaturated solid solutions. **Some Research Work Made in France and in the Sarre on the Martensitic Transformation of Metals.** C. Crussard. Published papers by Philibert and Crussard, Papier and Michel, and Bastien and Dedieu, and unpublished work by Hendus and Laurent and by Jolivet relating to the martensitic transformation of metals, are summarized.—G. F.

A New, High-Resolution X-Ray Fine Structure Apparatus with an Improved, Focusing Monochromator and Fine-Focusing Tubes. E.-G. Hofmann and H. Jagodzinski. (*Z. Metallkunde*, 1955, **46**, Sept., 601–610). A new high-resolution double chamber apparatus with an improved focusing monochromator and fine-focusing tube is described, and examples of its application given.—L. D. H.

The Double-Cone Method and its Suitability for Investigations on Deformation and Texture. H. Herglotz. (*Z. Metallkunde*, 1955, **46**, Sept., 620–622). The principle of Regler's double-cone camera is described, and some applications of its use are given.—L. D. H.

Collodion Replicas from Cross-sections of Thin Metallic Strip and Coatings. D. J. Evans. (*Brit. J. Appl. Phys.*, 1956, **7**, Feb., 65). An outline is given of a method of obtaining electron micrograph replicas by the use of collodion.—E. E. W.

A Comparison of Dry-Stripped, Unbacked Collodion and Formvar Replicas. D. J. Evans. (*Brit. J. Appl. Phys.*, 1956, **7**, Feb., 66–67). The ease and rapidity of preparation of collodion and its increased resolution over Formvar, commend its use for routine metallographic examinations.—E. E. W.

A Study of the Formvar Replica Process. A. W. Agar and R. S. M. Revell. (*Brit. J. Appl. Phys.*, 1956, **7**, Jan., 17–25). Tests were made on specimens of 0·6% carbon steel, austenized at 930° C for 30 min and then isothermally transformed at 675° C for 15 min. The surfaces were given various degrees of etching. The main conclusion is that this replica process is suitable for many classes of work although an approximately true replica is obtained only in rare cases.—E. E. W.

X-Ray Microscopy. W. C. Nixon. (*Research*, 1955, **8**, Dec., 473–483). The principles of X-ray microscopy, and the development of the reflection, contact, and projection types of instrument are described, with an appraisal of the advantages of each for various applications including those in metallurgy. (102 references).—K. E. J.

Micro-Radiographic Investigations on High-Speed Steel. H. Neff. (*Z. Metallkunde*, 1955, **46**, Sept., 614–615). Micro-radiographic examinations of sulphide inclusions is superior to photomicrography of etched specimens in that a larger

sample can be covered, and stereographic microphotographs can give a clearer impression of the spatial distribution of the inclusions.—L. D. H.

Plastic Laps for the Preparation of Specimens for Metallographic Examination. V. J. Haddrell, E. C. Sykes, and B. W. Mott. (*J. Inst. Metals*, 1955–56, **84**, Jan., 112–114). Experiments have shown that polythene bonded laps are very suitable for preparing specimens for metallographic analysis particularly in the final stages of polishing. Practical details of the preparation of the laps from polythene powder and of the polishing techniques developed are given.—B. G. B.

Macro-Etching of Iron and Steel. (*Metal Progress*, 1955, **68**, Aug. 15, 195–200). The practical techniques for the macroetching of iron and steel specimens are described together with examples of the interpretation of the results.

Study on Carbides in Practical Special Steels by Electrolytic Isolation. I. On Carbide in Ball-bearing Steel. T. Sato, T. Nishizawa, and Y. Honda. (*Tetsu to Hagane*, 1955, **41**, Nov., 1188–1192). [In Japanese]. The electrolytic extraction of carbide from steel containing 1·13% of C and 1·42% of Cr is described. Cr contents were as follows: in carbide from the steel annealed at 750° C for 5 h, 7·21%; in the ferrite, ~0·24%; and in the austenite at the quenching temperature ~0·9%. The Cr content of the carbide precipitated from the matrix in low-temperature (300–400° C) tempering was approximately the same as that of the matrix, but increased with increase of tempering temperature and holding time.

The Shape of Carbide Particles Precipitated in α-Iron. W. Pitsch. (*Acta Met.*, 1955, **3**, Nov., 542–548). [In German]. The precipitation of carbide in α-iron was studied by combining the methods of internal friction and electrical resistivity which yields a parameter dependent solely on particle shape. It is deduced that the particles are plate-like in shape and that coagulation takes place as the process proceeds. The results are compared with those obtained by electron microscope methods.—A. D. H.

Temperature-Dependence of the Free Energy of Solid Solutions. B. Ilschner. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 623–626). Expressions are given for the dependence of the free energy on temperature. The entropy contributed by lattice vibrations is referred to, and the evaluation of calorimetric measurements is briefly discussed.—A. C.

Electron Microscope Investigation of Changes in the Structural Constitution of a Chrome–Nickel–Molybdenum Steel Under Sustained Tension at 500°. F. Wever and A. Schrader. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 475–481). Optical and electron microscope investigations were carried out on steel containing 0·14% C, 0·77% Cr, 0·94% Mo, and 1·6% Ni. Air- and oil-quenched specimens were examined after prolonged annealing at 500° in both the loaded and the unloaded state. Evidence was obtained to indicate the important effect of the Mo_2C precipitate.—A. C.

Changes in the Structural Constitution of Chrome–Nickel–Molybdenum Steels Under Sustained Load in Creep Tests at 500°. A. Krisch and H.-J. Wiester. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 463–474). Variously heat-treated specimens containing 0·04–0·30% C, 0·5–0·9% Cr, 0·7–0·9% Mo, and 1·4–2·6% Ni were creep-tested. The fractures were examined, and the carbides were separated for micro- and radiological analysis.—A. C.

Preparation of Samples with a View to Microscopic Examination. (*J. d'Inf. Tech. Indust. Fonderie*, 1955, Sept., Supplement 1–5). Short notes on the preparation of metal samples (ferrous and non-ferrous) are given.—B. G. B.

Influence of the Composition of Bearing Steels on the Carbide Network. N. K. Ipatov, I. Ya. Aizenshtok, and L. D. Kossovskii. (*Stal'*, 1955, (8), 739–742). [In Russian]. The aim of the work described was to find the effect of various elements on the quantity of carbides formed in bearing steels and on the ease with which the carbide network can be made finer or removed after annealing. The statistical-analysis method was applied to the results of chemical analyses and network size determinations on numerous heats of a single type of bearing steel. Some heats of the steel with an elevated manganese content were also included, and, in addition, the influence of position in the ingot was studied.—S. K.

Studies on the Determination of Non-metallic Inclusions in Iron and Steel. II. Determination of Non-metallic Inclusions in Cast Iron. H. Gotô and T. Watanabe. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 228–231). [In Japanese]. The chlorine method for determining non-metallic inclusions was satisfactory for white iron, but not for grey, where high values were obtained for FeO and MnO. No improvement was found on raising the chlorination temp. to 400–450°, or by treating the chlorination residue with NH_4 citrate and HNO_3, but treatment with chlorine gas ensured correct results for malleable and nodular iron.—K. E. J.

Thermodynamic Investigation of Non-Metallic Inclusions in Steel. I (2). Behaviour of Aluminium, Silicon and Iron Nitrides and their Effect on Austenitic Grain Size of Steel. H. Sawamura and T. Mori. (*Tetsu to Hagane*, 1955, **41**, Nov., 1175–1178). [In Japanese]. Cf. *ibid.*, 1955, **41**, Oct., 1082. (34 references).

Recrystallization in Metals as a Recovery-Nucleated Process. A. J. Kennedy. (*Metallurgia*, 1955, **52**, Dec., 265–269). Some recent developments in ideas concerning the origin and characteristics of recrystallization nuclei are reviewed. These ideas appear to have much in common, notably in the important part sub-boundaries are considered to play in such processes. (33 references).—B. G. B.

The Tensile Properties of Single Crystals of High-Purity Iron at Temperatures from 100 to − 253° C. N. P. Allen, B. E. Hopkins, and J. E. McLennan. (*Proc. Roy. Soc.*, **A**, 1956, **234**, Feb. 7, 221–246). At temperatures down to − 124° C, single crystals of high-purity iron are fully ductile, giving chisel-edge fractures and 100% reduction in area. At − 196° C, depending on the orientation of the stress axis, the behaviour covers the whole range between fully ductile and brittle. At − 253° C, the crystals give cleavage fractures, without prior deformation over most of the orientation range studied. The variation of the resolved shear stress needed to produce slip or twinning at − 196° C is analysed by dislocation theory. The cleavage strength normal to the cleavage plane is not constant with temperature. (23 references).—K. E. J.

Crystal Growth—Molecular Phenomena. W. Kossel. (*J. Phys. Radium*, 1956, **17**, Feb., 95–106). An attempt is made, using spherical models, to show the geometry of crystal growth. A study of the growth of a silver thread by electrolysis shows that there is a formation of tiers whose depth is greater than the molecular thickness.—E. E. W.

Application of the Theory of Explosion Waves to the Growth of Martensite. C. Crussard. (*Compt. Rend.*, 1955, **240**, June 13, 2313–2315). It is well known that, in steels containing large grains, the formation of martensite is accompanied by clicks which are clearly audible. This qualitative observation, which has recently been expressed in precise terms, suggests that individual plates of martensite grow at a speed approaching that of sound. The possibility is indicated of comparing this growth to the propagation of an explosion wave.—G. E. D.

On the Velocity of a Martensite Crystal Growth. A. N. Alfimov and A. P. Gulyaev. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (3), 88–90). [In Russian]. An attempt to measure the time of the formation of a martensite crystal using a cathode oscilloscope is described. A cylindrical steel specimen (1·4% C and 2·9% Mn) with one flat face polished (to which a piezoelement was tightly fitted) was cooled in a vapour of liquid nitrogen. The time of the formation of a martensite crystal was assumed to be the duration of the pressure impulse which appears, due to the formation of relief on the polished surface during martensite transformation. The duration of the pressure impulse was shorter than that of the generator with which it was compared, $-1\cdot10^{-7}$ sec.—V. G.

Metallographic Investigation of Tempering of Hardened High-Carbon Steel. A. P. Gulyaev and M. P. Zel'pet. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Tekn. Nauk*, 1954, (3), 83–87). [In Russian]. Transformations which take place during tempering of high-carbon (1·38; 1·67%) steel of a coarse grain structure at temperatures 100–200–250–300–400–500° C were investigated using microscopical observations, microphotography (magnification × 1000) and microhardness measurements.—V. G.

New Intermediate Phase in Burnt Tungsten Steels. K. Kuo. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Feb., Section 2, 97). The author has identified a new phase in tungsten steels. It has β-manganese structure, is formed only by drastic quenching directly from the liquid state, and is a ternary phase of iron, tungsten, and carbon, with tungsten and carbon contents lower than in Fe_3W_3C.

The Alloys of Iron with Palladium and Platinum. Critical Examination of Publications. J. R. Knight and E. C. Rhodes. (*Rev. Mét.*, 1955, **52**, July, 518–528). The equilibrium dia-

grams of these alloys are critically examined from a study of experiments carried out to determine their magnetic, electrical, and physical properties. Certain iron–platinum alloys show a very high coercivity and low, even negative, coefficients of expansion. Alloys containing either element show an important positive magnetostriction. Comparison with the iron–nickel system is also made.—G. E. D.

Introduction to the Theory of Dislocations. A. A. Arantes. (*Bol. Assoc. Brasil. Met.*, 1954, **10**, Oct., 351–362). [In Portuguese]. A simple introduction to dislocation theory is given and its application to the phenomena of strain and age-hardening, recovery, and recrystallization is discussed. (21 references).—P. S.

Austenitic Fe–Cr–C–N Stainless Steels. G. F. Tisinai, J. K. Stanley, and C. H. Samans. (*Trans. Amer. Soc. Metals*, 1955, **48**, Preprint No. 7). Completely austenitic structures are formed at temperatures above about 1200° C in nickel-free steels containing 21–33% chromium provided proper additions of carbon and nitrogen are made. Rapid cooling retains the austenite but on slow cooling it decomposes to a mixture of ferrite, carbides, and nitrides. Methods of manufacture and certain properties are given.—E. E. W.

Dilatometric Study of $\alpha \rightleftharpoons \sigma$ Transformation in Iron–Chromium Alloys. P. Bastien and G. Pomey. (*Compt. Rend.*, 1955, **240**, Feb. 21, 866–868). The $\alpha \rightleftharpoons \sigma$ transformations are so slow that a dilatometric study often relates to metastable conditions. A dilation–temperature diagram for various metastable states is described which enables any curve met in practice to be interpreted.—G. E. D.

The Effect of Tungsten on the Isothermal Decomposition of Austenite in the Steel 25MnCrV. J. Cadek. (*Hutnické Listy*, 1955, **10**, (10), 587–595). [In Czech]. The four steels studied contained approximately 1·2% Mn, 1·1% Cr, 0·3% V, and variable amounts of tungsten, i.e. 0·0–2·8%. Metallographic, and X-ray methods were used, the latter primarily on the electrolytically separated carbide phase. S-curves were constructed. Tungsten was found to increase the stability of austenite in the ferritic-pearlitic stage considerably, but only very little in the bainitic stage. The domain of stability of austenite is enlarged. Precipitation of carbides in the hypo-eutectoid ferrite was observed to occur in all the steels; the austenite in the 2·8% W steel decomposed in a certain temperature range only with the simultaneous formation of both ferrite and carbide within it. The eutectoid phase does not appear in the process. The effect of tungsten on the stability of austenite in the ferrite-pearlite stage is considerably dependent upon the austenization temperature, and becomes insignificant below a certain content of tungsten. On the whole, raising the austenization temperature from 900 to 1300° C results in increased stability of the austenite in the ferrite-pearlite domain. Hultgren's hypothesis of the existence of " parapearlite " is shown to be untenable.—P. F.

Study of the Effect of Tungsten on Nucleation and Growth of Ferrite. K. Mazanec and A. Kalivoda. (*Hutnické Listy*, 1955, **10**, (10), 580–587. [In Czech]. The effect of tungsten on the rate of growth and the rate of nucleation of ferrite in two structural Cr–W–V steels was found to be a decrease of both rates over the whole range of temperatures studied, i.e. 650–740° C. The activation energy for the growth rate was 32 and 35 kcal/gm atom respectively, close to that of the diffusion of carbon in austenite. This indicates that the diffusion of tungsten plays no role in the ferrite reaction except in so far as it reduces the diffusion rate of carbon in austenite.

Effect of Heat Treatment of Titanium-Stabilised 18–9 CrNi Stainless Steel with Varying C/Ti ratio Upon its Resistance to Intergranular Corrosion. E. I. Astrov and V. N. Biryukova. (*Vestnik Mashinostrocniya*, 1953, **33**, (9), 61–65). [In Russian]. On the basis of results obtained, the optimum heating temperature for quenching titanium-stabilized 0·1% C, 18% Cr, 9% Ni stainless steel containing the lowest permissible percentage of titanium is recommended as being 1000–1050° C, if titanium content of steel is 5–6 times higher than its carbon content this temperature should be within the range 1050–1100° C, but not above 1150° C.—V. G.

Kinetics of the First Stage in the Decomposition of Martensite. G. Kurdyumov and L. Lysak. (*Zhur. Tekhn. Fiz.*, 1949, **19**, (5), 525–531). [In Russian]. An experimental investigation of the rate of the first stage of the decomposition of martensite (formation of nuclei of carbide particles accompanied by the formation of limited regions of lower-concentration solid solution around these particles), at various temperatures is described.—V. G.

A Phase Diagram for 1% Carbon Iron Alloys Containing up to 16% Nickel. P. Samuel, L. G. Finch, and J. R. Rait. (*Nature*, 1955, **175**, Jan. 1, 37–38). A short account of the derivation of this diagram is presented.—B. G. B.

Researches on the Fe–N System. A. Burdese. (*Met. Ital.*, 1955, **47**, Aug., 357–361). [In Italian]. The author studies the Fe–N system with particular reference to composition of the α- and γ'-phases and the $\epsilon \rightarrow \zeta$ transformation. The method used consists in nitriding in controlled atmosphere and using X-ray measurements on solids by means of a Geiger-counting spectrometer. The maximum limit of solubility of nitrogen in α iron is established at between 0·11 and 0·12%. The various limits of composition of the γ' phase (Fe_4N) are determined for different temperatures.—M. D. J. B.

The Magnetic Properties and Phase Diagram of the Iron–Tellurium System. S. Chiba. (*J. Phys. Soc. Japan*, 1955, **10**, Oct., 837–842). The Fe–Te system was examined by X-ray and thermal analysis. Several intermetallic compounds are formed, with a eutectoid reaction between two compounds. The compounds are antiferromagnetic.—J. G. W.

The Effect of Aluminium on the Sigma Formation in the Iron–Chromium System. M. Tagaya and S. Nenno. (*Techn. Rep. Osaka Univ.*, 1955, **5**, Mar., 149–152). The effect of aluminium additions, up to 4%, to Fe–Cr alloys containing 20–35% Cr, on the formation of sigma phase was studied by means of hardness tests and microscopical and X-ray analysis. No sigma phase was formed in alloys with less than 25% Cr; in 30% Cr alloys the rate of sigma formation was highest for 0·3% Al; no sigma phase was present in 35% Cr alloys with more than 1·26% Al.—J. G. W.

Effect of Ternary Additions of Silicon and Aluminium on the Ordering Reaction in Iron–Cobalt. A. J. Griest, J. F. Libsch, and G. P. Conard. (*Acta Met.*, 1955, **3**, Sept., 509–510). A letter. The effect of ternary additions of silicon and aluminium on the relation between the critical temperature of ordering and the solidus temperature was determined by thermal analysis.—A. D. H.

Diffusion and Solubility of Nitrogen in Silicon–Iron. D. A. Leak, W. R. Thomas, and G. M. Leak. (*Acta Met.*, 1955, **3**, Sept., 501–507). Internal friction methods have been used to determine the solubility of nitrogen in an iron alloy containing 2·83% Si. Relaxation peaks have been identified with the stress-induced jumps of nitrogen atoms to certain atomic sites. Over the temperature range 250°–1000° C the solubility is an order of magnitude less than for pure α-iron. The heat of solution of the precipitated nitride in equilibrium with the solid solution was 8 kcal/gm atom of nitrogen.—A. D. H.

Ordering and Magnetic Heat Treatment of the 50% Fe–50% Co Alloy. R. C. Hall, G. P. Conard, and J. F. Libsch. (*Trans. Amer. Inst. Min. Met. Eng.*, 1955, **203**; *J. Met.*, 1955, **7**, Sept., Section 2, 985–989). Experiments with a 50% Fe–50% Co alloy indicate that, during the disorder–order transformation at about 732° C, the coercive force goes through a maximum as a result of strains associated with the coherent nucleation and growth reaction. The marked increase in the ratio of residual to saturation induction is associated with annealing to a high degree of order in a magnetic field. The course of the ordering process, the response to magnetic anneal, and the relation between the two, are discussed.—G. F.

Colour Metallography of Ferrous Alloys. A. Scortecci and C. Durand. (*Met. Ital.*, 1955, **47**, July, 305–308). [In Italian]. The authors describe a method of colour metallography in which they combine the methods of attack by solution and oxidation by heating in air. The experimental techniques are discussed and the results obtained are described. 29 coloured photomicrographs are given. (41 references).—M. D. J. B.

The Lack of Crystal Boundary Hardening in Deformed Metals as Revealed by Microhardness Measurements. H. Tuchschmid. (*Acta Met.*, 1955, **3**, Mar., 215–216). Microhardness measurements on deformed 18/8 stainless steel and an aluminium alloy have shown that there is no hardening at the grain boundaries.—A. D. H.

On the Interpretation of " Low Temperature " Recovery Phenomena in Cold Worked Metals. A. S. Nowick. (*Acta Met.*, 1955, **3**, July, 312–321). A survey is made of recovery phenomena at temperatures at which equilibrium atomic diffusion is too slow to be the rate-controlling process in recovery. Recovery is then considered as a superposition of

first-order decay processes involving a spectrum of recovery times. (56 references).—A. D. H.

Dislocation Energies in Anisotropic Crystals. A. J. E. Foreman. (*Acta Met.*, 1955, **3**, July, 322–330). The elastic energy of a dislocation in a cubic or hexagonal crystal is calculated in terms of the orientation of the crystal to the dislocation line. The inelastic contribution of the dislocation core is also discussed.—A. D. H.

Some Observations of Dislocation Sites in Polygonized Silicon–Iron Crystals. C. G. Dunn and W. R. Hibbard, Jun. (*Acta Met.*, 1955, **3**, July, 409–411). The character of polygonized boundaries in 3¼% Si–Fe crystals which had been bent about the <112> axis is described and discussed.

Progressive Etching Effects on a Selected Area of Pearlitic Steel Revealed by the Electron Microscope. D. E. Bradley. (*Metallurgia*, 1955, **52**, Oct., 203–204). The technique described gives a very clear picture of the manner in which the etchant attacks the specimen. Applications are suggested.—B. G. B.

Using the Interference Microscope for Thickness Measurements of Decorative Chromium Plating. J. D. Thomas and S. R. Rouse. (*Plating*, 1955, **42**, Jan., 55–57). The theory and application of the interference microscope for the measurement of the thickness of chromium plating of the order of 1–2 × 10^{-5} in. is described. Methods of removing the chromium from a portion of the specimen to produce a bevelled boundary to show shifts of the interference pattern are given. The method may be used to supplement the spot-test.—A. D. H.

Study on High Chromium Steel. On the Anomaly of α Solid Solution of Fe–Cr System at High Temperature. II. Y. Imai and K. Kumada. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 204–207). [In Japanese]. The effects of long annealing at 500° C on hardness, dimensions, and magnetic properties were examined in specimens containing 15–74% Cr. The greatest changes in physical properties were found with chromium contents of approximately 25 and 35%.—K. E. J.

Temperature Dependence of Hardness of the Equi-Atomic Iron Group Aluminides. J. H. Westbrook. (*J. Electrochem. Soc.*, 1956, **103**, Jan., 54–63). The hardness of alloys based on the compounds FeAl, CoAl, and NiAl was studied at temperatures up to 800° C, using a low-load hardness testing instrument. The results are discussed in relation to the defect structure.—A. D. H.

The Alloys of Cadmium with Cobalt, Iron and Nickel. F. Lihl and E. Buhl. (*Z. Metallkunde*, 1955, **46**, Nov., 787–791). Alloys of cadmium with iron were prepared by amalgamation; on subsequent distillation at 360° C under pure hydrogen the mercury was completely removed after 2 h. Investigation of the alloys showed that cadmium and iron are immiscible in the solid state.—L. D. H.

On the Structure of Austenitic Mn–Cr and Cr–Ni Steels Used at High Temperatures. F. Pobořil, M. Knotek, and M. Zezulová. (*Hutnické Listy*, 1955, **10**, (12), 725–737). [In Czech]. The positions of technical Fe–Mn–Cr and Fe–Cr–Ni steels (stabilized with Ta, Nb, Ti, and V) in the ternary phase diagram were determined, and the extent of the gamma domain ascertained. The positions of the phase boundaries were checked by long time anneals of the steels at 800° C which, for those including the sigma phase, resulted in embrittlement. Equations for the conversion of alloy contents to Mn, Cr or Ni " equivalents " are given. By their use three types of economical stabilized Mn–Cr steels were developed.

The Iron–Phosphorus–Vanadium System. B. Stengel and R. Vogel. (*Arch. Eisenhüttenwesen*, 1955, **26**, Sept., 547–554). The thermally and microscopically determined equilibrium diagram is discussed. The section Fe_2P–V_2P proved to be pseudo-binary. The system is an example of a solid solution with unstable zones. The affinity of phosphorus for vanadium was found to exceed its affinity for iron. The diagram for the system Fe–Fe_2P–V_2P–V was constructed from the experimental results and theoretical reasoning based on them. The unstable eutectic crystallization of the solid solution $(Fe,V)_2P$ and its relation with the destabilization of the solid solution series $(Fe,V)_3P$ with medium vanadium content is explained.

The Iron–Phosphorus–Tin System. R. Vogel and G. Zwingmann. (*Arch. Eisenhüttenwesen*, 1955, **26**, Oct., 631–640). The authors describe thermal and metallographic investigations to determine the equilibrium diagram in the range iron–iron phosphide (FeP)–tin phosphide (Sn_4P_3)–tin. The following were found to be in equilibrium at room temperature: (1) Fe–Fe_3P–FeSn, (2) Fe_3P–FeSn–$FeSn_2$, (3) Fe_3P–Fe_2P–$FeSn_2$, (4) Fe_2P–$FeSn_2$–Sn, (5) Fe_2P–FeP–Sn, and (6) FeP–Sn_4P_3–Sn. The results indicate that the iron has a greater affinity for phosphorus than has the tin.—A. C.

The Iron Sector in the Iron–Beryllium–Phosphorus System. R. Vogel and G. Zwingmann. (*Arch. Eisenhüttenwesen*, 1955, **26**, Nov., 701–704). Structural and thermal investigations were made, and the equilibrium conditions were determined. In the Fe–Fe_2P–Be_2Fe zone, at 997°, a peritectic four-phase equilibrium was found, with 85% Fe, 4·75% Be, and 10·25% P, corresponding to the development of Fe_2P and Be_2Fe. For a combination of 88% Fe, 3·75% Be, and 8·25% P, a ternary eutectic was formed from Fe_2P, Be_2Fe, and ternary α-iron solid solution at 961°. The experiments showed that in the triangle Fe–Fe_2P–Be_2Fe, beryllium cannot extract the phosphorus from iron.—A. C.

CORROSION

Temperature Coefficient and Heat of Activation of the Corrosion Reaction for Buried Iron. T. Markovic, M. Karsulin, Z. Dugi, and D. Zagar. (*Werkstoffe Korrosion*, 1956, **7**, Mar., 138–139). From small-scale laboratory experiments, the authors conclude that the corrosion of iron by various soils can be defined in terms of the water/air ratio in the soil, the temperature coefficient of the reaction and its heat of activation. The average value of the temperature coefficient is 1·9 approx. for soils containing 20% of water or 1·7 approx. for saturated soils; at these two levels of water concentration the heats of activation vary, according to the soil, from 10 to 19 kcal or from 5 to 11 kcal, respectively.—J. C. H.

Survey of Methods and Specifications for Accelerated Climatic Tests. A. Kutzelnigg. (*Werkstoffe Korrosion*, 1956, **7**, Feb., 65–82). A praiseworthy, useful, but incompletely successful attempt to list and classify the whole of the literature on accelerated corrosion tests for metals, with particular regard to atmospheric attack. No discrimination or discussion is attempted.—J. C. H.

The Reactions between CuO and Fe or Fe_3O_4 in the Solid State and the Effects of Oxygen and Water Vapour on These. K. Wickert and H. Wiehr. (*Werkstoffe Korrosion*, 1956, **7**, Jan., 13–16). The scale deposited on the tubes of high-pressure boilers often contains copper or CuO. The authors have, therefore, studied the course of the reactions between CuO and Fe or Fe_3O_4, which may be present on the steel surface, by means of thermal analysis up to 600° C. The reaction CuO + Fe = FeO + Cu takes place more rapidly in presence of oxygen and steam.—J. C. H.

Method for the Conduct of Corrosion Tests. L. Riccoboni, P. Papoff, and I. M. Vezzosi. (*Werkstoffe Korrosion*, 1955, **6**, Dec., 569–571). An automatic apparatus for the quantitative study of the corrosion of metals by electrolytes is described. The method of measurement is based on polarographic determinations and is particularly suitable for following reactions in which dissolved oxygen is involved.

Laboratory Tests on the Cathode Protection of Buried Metals. T. Markovic. (*Werkstoffe Korrosion*, 1955, **6**, Dec., 580–581). The author concludes from laboratory experiments made in 200 ml glass vessels that buried steel can be protected completely cathodically by zinc only when both the coupled metals are exposed to conditions of restricted oxygen supply, such as occur when free access of oxygen is hindered because the soil is waterlogged.—J. C. H.

On the Variations in the Chemical Composition of Ferrous Oxide. J. Aubry and F. Marion. (*Compt. Rend.*, 1955, **240**, May 2, 1770–1771). The composition of non-stoichiometric ferrous oxide depends on the temperature and the atmosphere in which it is prepared. The field of equilibrium at a surface lies between two well-defined limits.—G. E. D.

On the Variations in the Chemical Composition of Ferrous Oxide. C. Chaudron. (*Compt. Rend.*, 1955, **240**, May 2, 1771–1772). The branch of the diagram corresponding to the equilibrium, ferrous oxide–magnetite is difficult to determine. Nevertheless, good agreement has been reached by several workers.—G. E. D.

Reaction of Iron with Oxygen at Low Pressures and at Temperatures between 650° C and 850° C. E. A. Gulbransen, W. R. MacMillan and K. F. Andrew. (*Rec. Mét.*, 1955, **52**, July, 509–517). Recent studies using electronic optical methods on the oxidation at low pressures of annealed and electrolytically polished specimens of Puron and Armco iron are summarized. Discontinuous oxidation is observed whether at a fixed initial pressure with limited amounts of oxygen or

at still lower temperatures with prolonged reaction times. Puron and Armco iron behave slightly differently due to the carbon present in the latter reacting more rapidly with the superficial oxide. Results are related to the substructure of the metal.—G. E. D.

Research on a Steel Permits the Exploitation of Deposits of Sulphurous Natural Gas. J. Dauvergne. (*Bull. Cercle Études Mét.*, 1955, **6**, Dec., 417–458). The difficulties which arise during drilling for natural gas containing hydrogen sulphide due to corrosion of the drill pipes are explained. Tests to measure the resistance of steel alloys to this form of corrosion are described. Results obtained on a large number of steels are considered.—B. G. B.

The Use of Demineralisation in Steam Raising Plant. P. Profos. (*Sulzer Tech. Rev.*, 1955, No. 2, 47–57). A short survey of the principal systems is followed by an account of the operation of two-bed and mixed-bed plant. Special reference is made to the quality of water obtained and methods of regeneration.—B. G. B.

Corrosion Control in Oil and Gas Producing Equipment. J. L. Gattenmeyer, F. W. Hewes, and W. H. Seager. (*Canad. Min. Met. Bull.*, 1956, **49**, Jan., 31–36). Corrosion mechanisms are outlined. Places in oil or gas fields where corrosion might occur are indicated, with particular reference to the Alberta fields. Corrosion preventive methods for gas and oilfield equipment are described.—T. E. D.

Sprayed Aluminium Coatings. U. R. Evans. (*Chem. Indust.*, 1956, Mar. 24, 195–196). An experiment is described which proves that sprayed aluminium coatings can afford cathodic protection to steel.—E. E. W.

A Method of Protecting Pipe Type Cables. F. E. Kulman. (*Corrosion*, 1955, **11**, Nov., 13–14). Cathodic protection and fault current grounding have been simultaneously provided to steel pipe carrying cables through a stainless steel resistor and a rectifier.—J. F. S.

Atmospheric Corrosion by Nuclei. R. St. J. Preston and B. Sanyal. (*J. Appl. Chem.*, 1956, **6**, Jan., 26–44). Experiments were made to determine the conditions which favour filiform corrosion on bare and on varnished steel. Various inorganic salts were used as nuclei and the effect of relative humidity was studied. The effect of certain pre-treatments is considered.—E. E. W.

Corrosion and Corrosion Protection in Ship Construction. K. Sautner. (*Z.V.d.I.*, 1955, **97**, Aug. 1, 747–752). The various types and locations of corrosion in ships are described followed by a discussion of the appropriate methods of preventing or combating corrosion including cathodic protection and the 'electro-coating' process.—J. G. W.

Metallic Zinc as Corrosion Protector. R. Haarman. (*Metall*, 1955, **9**, Aug., 646–648). The anticorrosive properties of hot-dip galvanizing, electrolytic galvanizing, zinc spraying, painting with zinc paint, sherardizing, and the rise of zinc in cathodic protection are briefly reviewed.—J. G. W.

Practical Use of Zinc Anodes for the Cathodic Protection of Conduits. B. Trautmann. (*Metall*, 1955, **9**, Aug., 649–651). The mechanism of cathodic protection, application of zinc anodes for the purpose, and the design of installations are discussed.—J. G. W.

Corrosion Protection by Cold Galvanizing. I. C. Fritz. (*Metall*, 1955, **9**, June, 488–489). The method of coating by means of zinc-rich paints, the nature of the coating and its anticorrosive value, are discussed.—J. G. W.

Special Corrosion Problems of Electric Utility Systems. C. F. Avila and A. B. Jones. (*Corrosion*, 1955, **11**, July, 19–22). Several cases of outdoor corrosion of electric power companies' plant are described. These involved corrosion cracking, galvanic action, ground line corrosion of standpipes, and corrosion resulting from other design faults. Full details are given for construction and protection of a successful zinc sprayed subway transformer tank.—J. F. S.

Corrosion in the Petroleum Industry. F. H. Garner and A. R. Hale. (*Corrosion Techn.*, 1955, **2**, May, 143–146; June, 177–180; July, 218–220). The authors discuss ways in which corrosion attacks various parts of a refinery and describe some of the equipment and metals used to combat these attacks. Methods for treating corroded parts are also discussed and the authors conclude with a consideration of the problems involved in the handling of hydrofluoric acid, aluminium chloride, alkalis, chlorinated solvents, phenol, sulphur dioxide, etc. (24 references).—L. E. W.

Coatings and Cathodic Protection for Steel Pipelines. G. I. Russell. (*Corrosion Prevention and Control*, 1955, **2**, Apr., 21–26; May, 21–24). The author expounds his views on the dual importance of cathodic protection and high quality coatings in pipeline anti-corrosion maintenance practice. Design factors are discussed and where cathodic protection has failed the probable reasons are given. Line currents, aggravated attacks, etc. are dealt with and the author concludes by considering the economic factors involved in protecting pipelines.—L. E. W.

Current Status of Corrosion Mitigation Knowledge on Sweet Oil Wells. (*Corrosion*, 1955, **11**, Oct., 61–63).

Cathodic Protection Installations at Kwinana. K. A. Spencer. (*Corrosion Prevention and Control*, 1955, **2**, July, 23–27). The author describes how cathodic protection has overcome the corrosion problems at the Kwinana Refinery (Western Australia) which has a large number of marine structures.—L. E. W.

Electrochemical Investigations of the Corrosion of α-Iron Crystals in Diluted Acids. H.-J. Engell. (*Arch. Eisenhüttenwesen*, 1955, **26**, July, 393–404). Anodic partial current–voltage curves for the corrosion of α-iron crystals in dilute sulphuric, perchloric, and nitric acids show that at low current densities (up to about 2 mA/cm²) the rate of solution is independent of crystal orientation. At higher current densities the octahedral faces dissolve most, and the cubic faces least rapidly. Other faces fall between these extremes. In corrosive media demanding high current densities the variously orientated crystals in a colony act as local anodes and cathodes, causing considerably stronger attack on the crystal boundaries. On cubic faces, low current densities produce cubic, and high current densities produce octahedral pitting. The implications of Kossel and Stransky's theory are not entirely borne out. The current–P.D. curves are explained on the assumption of an adsorption layer in which iron ions are held with comparative strength. At low current densities the approximate equilibrium between the metal and the adsorption layer is predominant, and escape from the layer into the electrolyte determines the current. At this stage, dissolution is only slightly dependent on surface orientation. At higher current densities the fall in potential reduces the barrier between the adsorption layer and the electrolyte, and transit is affected by the orientation of the surfaces. The results permit some general conclusions to be drawn.—A. C.

Corrosion Research in U.S.S.R. (*Corrosion Prevention and Control*, 1955, **2**, Dec., 35–38). The conclusions and theories advanced by Russian investigators concerning the tendency of stainless steel to inter-crystalline corrosion and the fatigue strength of steel are critically examined.—L. E. W.

Magnetic Water Treatment Apparatus—Notes on its Effectiveness. J. Laureys, J. Van Muylder, and M. Pourbaix. (*Corrosion Techn.*, 1955, **2**, Oct., 312–316). The authors describe apparatus used for their study of encrusting action of water and outline the working method finally adopted. The results obtained with untreated and magnetically treated (method of treatment not indicated) waters are given and discussed.—L. E. W.

Corrosion Problems in Dyeing and Finishing Works. A. J. Hall. (*Corrosion Techn.*, 1955, **2**, Oct., 307–311). The author indicates the complexity of the corrosion problems that can occur in textile dyeing and finishing works and shows how the products of metallic corrosion can be transferred to fabric. There is a discussion of likely corrosion environments with particular reference to the dyehouse roof. Materials of construction are considered from the point of view of corrosion. Wood decay and steam-pipe corrosion are also dealt with.

The Painting of Ships. T. A. Banfield. (*Corrosion Techn.*, 1955, **2**, Oct., 302–306, 316). The author describes briefly the pre-treatment of underwater and above water parts of ships, then deals with the types of priming and finishing paints suitable for anti-corrosive and anti-fouling. The conditions of application are also considered. (12 references).

Bitumen in the Prevention and Control of Corrosion. R. P. Bell and K. A. Wheeldon. (*Corrosion Prevention and Control*, 1955, **2**, Oct., 30–34; Nov., 33–38). The origin of bitumen and its production are outlined. The basic properties of bitumen in relation to corrosion prevention are discussed, and the general compositions of bitumen paints, their relative merits, and methods of application are dealt with.—L. E. W.

Electrochemical and Chemical Factors in Wet Corrosion. B. Le Boucher. (*Métaux–Corrosion–Indust.*, 1955, **30**, Sept.,

324–339). The electrochemical principles of the corrosion of metals in aqueous media are reviewed. Factors which accelerate the rate of corrosion (reduction of *p*H, increase in oxygen content in the liquid, reduction of anodic polarization, draining off the anodic current) are described. Electrical methods of measuring the rate of corrosion are explained.

Lead-Base Paints in the Fight Against Rust. J. L. Rabaté. (*Peintures, Pigments, Vernis*, 1955, **31**, Sept., 776–786). The efficacy of a wide range of paints containing lead in different chemical forms is discussed. The formulations of the paints are given and the reasons for the satisfactory performance of lead-based paints are considered.—B. G. B.

Corrosion of Metals in the Tropics. H. R. Ambler and A. A. J. Bain. (*J. Appl. Chem.*, 1955, **5**, Sept., 437–467). Tests made at various sites in Nigeria prove that corrosion is no greater in the tropics than in temperate climates. When there is no industrial pollution, the governing factor is airborne salt. The rate of corrosion of ferrous metals varies little between wet and dry seasons or between day and night, and is proportional to the rate of deposit of salt on a damp textile surface. The corrosion of steel in tropical tidal waters is twice as fast as in continuous immersion.—E. E. W.

The Effects of Repeated Washing of Tinned Steel with Alkaline Solutions on its Resistance to Rusting. S. C. Britton and D. G. Michael. (*J. Appl. Chem.*, 1955, **5**, Aug., 402–414). Continuous immersion for some hours resulted in comparatively small differences between the effects of various alkaline solutions on tinned steel. The results of intermittent action depended on the period of immersion and other operational conditions. A high rate of corrosion occurred between the removal of the metal from solution and rinsing. The deterioration in the protective quality of the coating can be predicted only moderately well from measurements of corrosion rate of tin immersed in the solution. The effects of various solutions are discussed.—E. E. W.

The Carburization of Iron Oxide with Carbon Monoxide: Modifications of Hägg Iron Carbide. E. M. Cohn, E. H. Bean, M. Mentser, L. J. E. Hofer, A. Pontello, W. C. Peebles, and K. H. Jack. (*J. Appl. Chem.*, 1955, **5**, Aug., 418–425). Carburization of reduced iron with carbon monoxide gives a normal Hägg iron carbide with a Curie point of 245–250° whereas that obtained from iron oxide and carbon monoxide gives a carbide with a Curie point of 276°. The latter carbide progressively approaches the 'normal' form with increasing temperature and time of carburization. Possible explanations are given.—E. E. W.

The Protection of Structural Steel—The Use and Weldability of Aluminium Sprayed Steel. H. F. Tremlett and W. A. Johnson. (*Chem. Indust.*, 1955, Dec. 10, 1616–1617). The advantage of spraying steel sections at the rolling mill cannot be fully utilized unless the parts can be used for welded construction without first having to remove the coating where the welds are made. A series of tests is described in which it was hoped to establish the conditions under which satisfactory welds could be produced.—E. E. W.

Protection of Cooled Parts of Open-Hearth Furnaces by an Electrolytic Polishing Method. A. P. Rogach, A. S. Romanenko, and A. M. Kargin. (*Stal'*, 1955, (8), 748–752). [In Russian]. A method, tested in the laboratory and on a working O.H. furnace, is described in which water-cooled metal surfaces are protected from corrosion and scaling by electrolytic polishing. The metal surface is made the anode, the cooling water being the electrolyte, and a current is passed at 0·002–0·003 amp/sq. dm. (for medium and very hard water). During the tests this technique reduced the thickness of the deposit of calcium and magnesium salts to 1/3–1/4 of the normal value. The current consumed for the protection of all the water cooled parts of a furnace is 2–3 kWh per day.—S. K.

Acid Contamination as a Source of Error in Boiling Nitric Acid Test for Corrosion-Resistant Steels. R. J. Bendure. (*Amer. Soc. Test. Mat. Bull.*, 1955, July, 76–77). High and erratic penetration rates were obtained when the testing area inadvertently contained hydrofluoric acid left over after etching.—B. G. B.

Control of Couples Developed in Water Systems. G. B. Hatch. (*Corrosion*, 1955, **11**, Nov., 15–22). Inhibition of the corrosion of ferrous metals in water systems is difficult if copper or its alloys are present. Experiments are described showing the breakdown of the mechanism of inhibition by glassy phosphates in the presence of traces of dissolved copper. A sodium–zinc phosphate glass (Calgon T) can be used successfully with 2-benzothiazolethiol to inhibit corrosion of ferrous metals in water systems containing copper and iron parts mixed. Accurate control of pH is not required.—J. F. S.

ANALYSIS

The Mechanism of the Dissolution of Metals in Nitric Acid. T. G. O. Berg. (*J. Chim. Phys.*, 1956, **54**, Feb., 169–181). Rates of dissolution of copper, molybdenum, iron, aluminium, nickel, and iron–chromium alloys in nitric acid, and iron and aluminium in hydrochloric acid were measured. A dissolution mechanism, common to all metals and agreeing well with experimental results, is derived.—T. E. D.

The Rates of Dissolution of Iron and Iron–Chromium Alloys in Nitric Acid. T. G. O. Berg. (*J. Chim. Phys.*, 1956, **54**, Feb., 163–168). Rates of dissolution in 0·25 N to 10 N nitric acid were measured for 0·12% C mild steel, and iron–chromium alloys containing 0·5, 1, 2, 4, 8, and 13% Cr at temperatures of 25, 35, 45, 55, and 65° C. Results are quoted and interpreted. The rate-controlling factors for the 4, 8, and 13% Cr alloys are different from those for Armco iron, mild steel, and the 0·5, 1 and 2% Cr alloys.—T. E. D.

Application of Radio-active Elements to Problem of High Purity Metals. P. Albert. (*Chim. Ind.*, 1956, **75**, Feb., 275–286). The use of radioactive tracers to determine the last tracers of impurities in iron and aluminium is described. The technique allows the rate of purification to be measured and an example of the application to the elimination of carbon from iron by annealing in pure hydrogen is given.

Influence of the Physico-chemical State of an Element on its Optical Spectrum. H. Triché and J. Simon. (*Compt. Rend.*, 1955, **240**, May 23, 2064–2066). The spectra of ferrosilicons and ferroborons show a reinforcement of the lines if they are compared with the spectrum of pure iron, although it does not consist of a volatile oxide due to reaction between the electrode and the initially formed gas. That the reinforcement of the lines is due to a more rapid pulverization is confirmed by direct experience with cathodic pulverization. The nature of the atmosphere in which the discharge takes place is also important.—G. E. D.

Study of the Estimation of Silicon and Phosphorus by the Photometry of their Molybdate Complexes. M. Jean. (*Chim. Analy.*, 1956, **38**, Feb., 37–49). The method is studied in detail and the results are examined critically, with particular reference to the determination of silicon and phosphorus in steel.—T. E. D.

Photometric Method of Determining Cobalt in Steels Based on the Red-Orange Colouration of Cobalt Salts by β-Nitroso-α-Naphthol. F. Jungblut. (*Chim. Analy.*, 1956, **38**, Feb., 49–54). The method is described. The principal factors influencing accuracy are examined, and dispersion of results is given. The method is rapid (40 min), precise, simple, economical, and of wide application.—T. E. D.

Colourimetric Determination of Molybdenum in Stainless and Chrome–Molybdenum Steels by Means of Phenylhydrazine. L. Pennac, A. Mutte, and M. Monnier. (*Chim. Analy.*, 1956, **38**, Mar., 94–95). Acid solutions of Mo (VI) treated with phenylhydrazine hydrochloride in acetic acid medium develops a stable and reproducible red complex. A simple and rapid method requiring no separations or extractions is described. Tolerances for interfering elements are given.—T. E. D.

Polarographic Determination of Ferrous and Ferric Iron in Refractory Minerals. G. S. Bien and E. D. Goldberg. (*Analy. Chem.*, 1956, **28**, Jan., 97–98). After fluxing the material with sodium metafluoroborate, it is dissolved in an electrolyte complexing both ferrous and ferric ions with citrate. The composite wave of oxidation and reduction of the complex ions gives an anodic current proportional to the concentration of ferrous iron and a cathodic current proportional to the concentration of ferric iron. The method is fully described.

New Iodometric Determination of Cobalt Based on Formation of Iodopentammine-Cobalt (III) Nitrate. R. G. Yalmann. (*Analy. Chem.*, 1956, **28**, Jan., 91–93). The determination of cobalt (II) by this method, in which oxygen need not be excluded, and in which the end-point is indicated potentiometrically or using starch, is described in detail. Copper and nickel do not interfere, nor do aluminium, iron, and chromium in the presence of tartrate.—T. E. D.

Amperometric Determination of Vanadium. C. L. Rulfs, J. Lagowski, and R. E. Baker. (*Analy. Chem.*, 1956, **28**,

Jan., 84–86). A rapid amperometric procedure for determination of vanadium to ± 1% in titanium-base alloys and alloy steels is described. Iron, chromium, manganese, and small amounts of molybdenum do not interfere.—T. E. D.

On the Determination of C and S in Steel with High Frequency Induction-Heating Furnace. I. M. Arakawa, K. Yasui, and T. Fujie. (*Sumitomo Metals*, 1955, **7**, Oct., 218–227). [In Japanese]. The use of an induction-heated instead of a resistance-heated furnace leads to higher combustion temperatures, and good melting and mixing effects. The time for determinations of carbon and sulphur is reduced to one-third to one-half.—K. E. J.

Determination of Oxygen in Cast Iron. H. Gotô, S. Susuki, J. Kimura, and A. Onuma. (*Tetsu to Hagane*, 1956, **42**, Jan., 49–52). [In Japanese]. Successful results, in comparison with standard specific methods for each inclusion, were obtained in determining each oxide in cast iron by a fractional vacuum-fusion method. A tin bath was used; FeO, MnO, SiO_2, and Al_2O_3 were extracted at 1050, 1150, 1450, and 1750° C, respectively.—K. E. J.

Studies on Spectrophotometry. VI. Determination of Cobalt in Steel with Potassium Ferricyanide. Y. Oka and S. Ayusawa. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Apr., 224–228). [In Japanese]. Co can be determined from measurement of the absorption in the range 500–650 mμ of the coloured solution formed by adding $K_3Fe(CN)_6$ to ammoniacal solutions of cobalt. Iron salts do not interfere, but chromate and tungstate ions must be removed.—K. E. J.

Modern Rapid Methods of Chemical Analysis for Quality Control. H. C. Swett. (*Reg. Tech. Meet. Amer. Iron Steel Inst.*, 1955, 151–160). Details are given of some of the rapid analytical methods used at the Bethlehem Pacific Coast Steel Corporation. They include spectrographic methods, magnetic and combustion methods of carbon determination, and the combustion method of sulphur determination.—G. F.

The Rapid Determination of Minor Constituents in Steels. Using a Concentration Method. A. Zörner, E. Krath, and H. Feucht. (*Tech. Mitt.*, 1955, **4**, Dec., 237–243). Concentration of minor elements is achieved by partial precipitation of iron with ammonium hydroxide, the minor constituents being co-precipitated. Magnetic sedimentation is used for settling and washing the precipitate which is then used for determining the following elements by usual methods: aluminium, titanium, chromium, vanadium, molybdenum, tungsten, zirconium, and antimony. (15 references).—R. P.

Practical Methods for the Identification of Steels. H. E. Boyer. (*Ing. e Indust.*, 1955, **23**, Oct., 83–86). [In Spanish]. It is explained how the application of a series of simple tests enables the consumer to sort out unlabelled steels. The value of spot tests, permanent magnet tests, heat-treatment, hardness, and spark tests are discussed and illustrated by describing the results of these tests on a batch of seven different steels.

The Colorimetric Determination of Lead in Effluents. E. J. Serfass and R. M. Muraca. (*Plating*, 1955, **42**, June, 751–754). A colorimetric method of determination of 5–50 p.p.m. Pb by using diphenylthiocarbazone (dithizone) in effluents is given.—A. D. H.

The Determination of Sulphur in Plain Carbon Steel. R. Belcher, D. Gibbons, and T. S. West. (*Analyst*, 1955, **80**, Oct., 751–754). The sulphur is precipitated as $BaSO_4$ after most of the ferric iron has been extracted from HCl solution with isoamyl acetate. The $BaSO_4$ is filtered off and dissolved in an excess of ammoniacal ethylenediaminetetra-acetic acid (EDTA); the unused reagent is titrated with $MgCl_2$ solution using Solochrome black as indicator.—T. E. D.

An Improved Barium Sulphate Method for the Determination of Sulphur in Steel. B. Bagshawe and A. L. Pill. (*Analyst*, 1955, **80**, Nov., 796–802). Errors which occur when estimating sulphur in steel are discussed, with particular reference to chromium steels. The improved method, in which residual nitrate is decomposed with hydroxylamine hydrochloride, is described in detail. The accuracy is to within 0·002% in normal sulphur ranges.—T. E. D.

Colorimetric Determination of Combined Carbon in Cast Iron. A. Jamieson. (*Foundry*, 1955, **83**, Oct., 132–134). A colorimetric method for determining the combined carbon content of cast iron is described in detail. The sample is dissolved in a mixture of sulphuric, orthophosphoric, and nitric acids, the solution is filtered, diluted, and then transferred to the photoelectric colorimeter.—B. C. W.

Modern Methods of Analysis in Steelworks Laboratories. P. Enghag. (*Värm. Bergsmann. Ann.*, 1955, 17–44). [In Swedish]. A review of the principles and applications of various analytical methods and of associated equipment, deals with potentiometric methods; *p*H determination, by means of glass electrodes, direct-reading meters, potentiometric titrations; photometric methods: correlation between light absorption and content, production of monochromatic light, and extinction measurements; ion-exchange methods; chromatography; and emission spectrography.—G. G. K.

Determination of Gases in Steels and Cast Irons by Vacuum Melting. M. Signora and F. Baldi. (*Chim. e Indust.*, 1955, **37**, Sept., 794–801). [In Italian]. The authors describe the apparatus used and the modifications introduced to make it more practical and reliable. A detailed account is given of the results obtained on a number of steels and cast irons. The results obtained with the cast irons show up certain inconsistencies which are accounted for by the presence of methane in the gas extracted. (12 references).—M. D. J. B.

Determination of Niobium and Tantalum, Molybdenum, Tungsten, Titanium and other Components of Stainless Steels. S. Vivarelli. (*Chim. e Indust.*, 1955, **37**, Dec., 1026–1028). [In Italian]. The author proposes a polarographic method of determining niobium in steels. By attacking the sample with perchloric acid a precipitate containing all the niobium in the form of niobic acid is obtained. The precipitate is then dissolved and the niobium determined by polarographic means in a solution of concentrated hydrochloric acid in the presence of glycol. (31 references).—M. D. J. B.

Extension of the Lingane–Karplus Method of Potentiometric Determination of Mn to High Silicon Ores and Steels. L. Braicovich and M. F. Landi. (*Met. Ital.*, 1955, **47**, Dec., 559–564). [In Italian]. The methods of titration of Mn normally adopted in classical chemistry present a number of difficulties due to the presence of foreign ions in the solution, to the lack of stoichiometry in the reactions and to experimental difficulties. The authors show that these difficulties can be overcome by extending the Lingane–Karplus method to the wider field of steel products and raw materials. Products with high silicon contents are considered. Perchloric acid is shown to be the best etching agent since by means of the H*F* it eliminates the C and CO_2 as well as the SiO_2. Titration, which can be easily followed potentiometrically, occurs by reaction between the Mn^{2+} and the permanganate at a controlled *p*H (6 to 7) in the presence of pyrophosphate with formation of a pyrophosphate combination with Mn^{2+} giving a bright violet colour. The results obtained and described in this paper are considered to be good and readily reproducible.

Recent Advances in Analytical Chemistry of Iron and Steel. T. Somiya. (*Tetsu to Hagane*, 1955, **41**, July, 823–830). [In Japanese]. An account is given of recent co-operative work in Japan on standardization of methods of determination of gases and non-metallic inclusions in iron and steel, rapid analytical methods, electrochemical and spectrographic methods, statistical techniques, etc. Tabulated notes are given for approx. 80 analytical methods.—K. E. J.

Complexiometric Titrations XVI. The Determination of Bismuth, Nickel and Cobalt with Pyrogallol Red. V. Suk, M. Malát, and A. Jeníčková. (*Chem. Listy*, 1955, **49**, (12), 1798–1801). [In Czech].

Increase of Precision in Spectrochemical Analyses of Steels Obtained by the Use of an Electronically Controlled High Voltage Source. Á. Bardócz and F. Varsányi. (*Acta Techn.*, 1955, **13**, (3–4), 409–420). Tests on the reproducibility of analyses of the alloy content of steels with electronically controlled high voltage spark sources giving rectified sparks of 50 or 100 cycles/sec, and with a 50 c/s spark source controlled by a rotary synchronous switch, showed the 100 c/s source to be the best, the mean error in the analyses being of order ± 2%.—P. F.

Determination of Total Sulphur in Coal: An International Standard Method. P. J. Jackson. (*Fuel*, 1956, **35**, Apr., 212–229). Investigations leading to the preparation of a Draft Recommendation for an internationally acceptable method of the Eschka technique are described. (42 references).

Physicochemical Studies on Dusts. IX. Analysis of Siliceous Dusts: Effect of Various Inorganic Ions on the Determination of Dissolved Silica by the Molybdenum-blue Method. A. Prentice and P. D. Ritchie. (*J. Appl. Chem.*, 1956, **6**, Jan., 21–25). The recorded silica concentration is decreased linearly

with increasing concentration of ferrous and ferric ions. Ferrous ion is oxidized on precipitation of the hydroxide to form ferric molybdate which interferes.—E. E. W.

INDUSTRIAL USES AND APPLICATIONS

The Construction of Undercarriage Parts Using a Very High Strength Ni–Cr–Mo Steel, 35N.C.D.16. A. Daubert. (*Rev. Nickel*, 1955, **21**, Oct.-Nov.-Dec., 84–91). The space and strength requirements of the undercarriage are given, and choice of steel is discussed. The use of ultra-high-strength steels in the construction of American aircraft is examined.

The Rail as Criterion of Quality of Basic Bessemer Steel. R. Chavanne. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sc. 4, 1–29). Respective uses of basic Bessemer and open hearth steels are discussed and the properties and specifications of various metals are outlined. The production and quality requirements of railway rails are described together with methods of testing and causes of rail failure. Comparison is made between American, French and German practices and standards of rail quality. Twelve tables show rail data and specifications from a wide selection of countries but the tables are practically illegible due to poor reproduction.—E. C.

Selection of Canning Materials for Reactors Cooled by Sodium/Potassium and Carbon Dioxide. A. B. McIntosh and K. Q. Bagley. (*J. Inst. Metals*, 1955–56, **84**, Mar., 251–270). Factors affecting the selection of materials for atomic reactors cooled by sodium/potassium and carbon dioxide are discussed. An account of theoretical considerations and experimental investigations is given. Of the materials readily available only stainless steel can be considered for use at the highest temperatures for gas cooled thermal reactors. The successful use of stainless steel at temperatures of about 600° C may depend on the development of a barrier to eliminate the effects of diffusion between uranium and the can.—B. G. B.

Steel Castings—Their Engineering Advantages in Weldments. E. J. Wellauer. (*Trans. Amer. Found. Soc.*, 1955, **63**, 569–574). The use of steel castings in welded structures is discussed and the advantages in quality, reduced costs and design that can be obtained by this method of construction are emphasized.

High-Strength Steel. J. Dietz and L. H. McCreery. (*Aircraft Prod.*, 1956, **18**, Feb., 74–77). Experience of Chance Vought Aircraft, Inc., Dallas, Texas, in the use of ultra-high-strength steel in aircraft components is described. Design, heat treatment, plating, testing, and machining are considered. An ultimate tensile strength of 260,000 lb/sq. in. is mentioned.

Ultra-High-Strength Steels. K. J. Irvine. (*Aircraft Prod.*, 1956, **18**, Mar., 84–89). Some of the characteristics of steels in the tensile strength range 100 to 150 tons/sq. inch are examined and discussed, including ductility, fatigue properties, and heat treatment behaviour. Applications in the aircraft industry are mentioned.—T. E. D.

Joint Metallurgical Societies' Meeting in Europe, 1955. Technical Sessions in Düsseldorf: Manufacture and Service Performance of Rails. W. Jänicke. (75–80). The author describes the section design and specification of the different types of rails used in Germany for various service conditions, and outlines the method of manufacture. The development of welded track lengths is discussed and some of the defects observed in rails are described. **Steel Quality and Standardisation.** F. Brühl. (85–89). The author outlines the extent of standardization of steel specifications in Germany, discussing both the advantages gained and also some of the problems encountered.

The Selection of Sheet Steel for Formability. (*Metal Progress*, 1955, **68**, Aug. 15, 1–11). Factors affecting the selection of cold rolled and hot rolled low carbon sheet steels for stamping are discussed. Mechanical properties are correlated with formability and the percentage stretch of the metal in the die is taken as a measure of the severity of working. The effect of surface finish, anisotropy, grain size, ageing, speed of working, die design, and lubrication are considered.—B. G. B.

The Selection of Material for Press Forming Dies. (*Metal Progress*, 1955, **68**, Aug. 15, 12–20). The forming operations considered involve bending and moderate stretching of sheet. Dies for deep drawn working are not considered. The selection of die material is based on the previous performance of similar tools in similar operations. Typical selections for 504 specific sets of conditions are given.—B. G. B.

Technical Sessions in Paris: Steels for Prestressed Concrete. M. Guyon. Recent developments in the pre-stressing of concrete by means of stressed steel sections are reviewed, and the desirable properties of the steel used are discussed. **The French Thomas Steel Rail.** Colnel, Palme, and R. Borione. An outline is first given of the steelmaking and rolling procedure in the manufacture of rails from Thomas steel in France. Next the severe inspection procedure is described, and information on conditions of use is given. Finally, a description is given of some of IRSID's investigations carried out for the Joint Commission for Rails.—G. F.

ECONOMICS AND STATISTICS

Characteristic Factors as Bases of Evaluation of Efficiency in Management. F. Wesemann. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1745–1749). Characteristic factors for costing and general management are discussed and examples given.—A. C.

Importance and Methods of Costing in Ferrous Industry. K. Küpper. (*Stahl u. Eisen*, 1955, **75**, Dec. 29, 1750–1755). The history of costing in German ferrous industry is given, and the fundamentals and development of costing methods are discussed.—A. C.

The Luxembourg Iron and Steel Industry. (*Metal Bull.*, 1956, Mar. 6, 11–14). A short account of the industry is presented. 51% of the working population are employed in the iron and steel industry. Basic Bessemer steel is the principal product.—B. G. B.

Contribution of Iron and Steel to District's Property. (*Times Rev. Indust.*, 1956, **10**, Jan., 59–61). A short account of the development of the iron and steel industry of Tees-side is presented.—B. G. B.

Metal Working in Colombia, South America. G. X. Diamond. (*Metal Progress*, 1956, **69**, Jan., 97–101). A short description of iron foundry and steel making practice in Colombia is given.—B. G. B.

Steel in France. H. W. Stokes. (*Canad. Metals*, 1955, **18**, Dec., 10–12). A very brief account of the French Iron and Steel Industry is presented.—B. G. B.

Russia's Progress—and Shortcomings. (*Metal Bull.*, 1956, Jan. 24, 9–10; Jan. 27, 14–15). A short account of Russian progress in the iron and steel industry is presented.—B. G. B.

Coal, Iron, and Steel—The Foundations of German Industry. F. Blücher. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1417–1421). The author points out that the primary material-producing industries depend on the supply of raw material, and that to avoid transport costs they tend to introduce plant for more advanced processing of their products. He reviews the influence of technical development and geographical location, and refers briefly to new materials competing with iron and steel.—A. C.

Light Metals in Competition with Steel. P. Brenner. (*Stahl u. Eisen*, 1955, **75**, Oct. 20, 1364–1375). Aluminium and magnesium are compared with other metallic materials, in particular with steel. The physical, mechanical, and chemical properties of the light metals and their alloys are reviewed, and their uses and methods of combination are discussed. The range of utility of light alloys as competitors with other metallic materials is estimated, and examples of advantageous supplementary uses for both steel and light alloys are given.

MISCELLANEOUS

Electromagnetic Suspension of a Molten Zone. W. G. Pfann and D. W. Hagelbarger. (*J. Appl. Phys.*, 1956, **27**, Jan., 12–18). A description is given of a new method of suspension and some experimental results and practical considerations are discussed.—E. E. W.

Dust and Health in Industry. (*Advancement Sci.*, 1956, **12**, Mar., 411–418). Abridged accounts of four papers on this subject presented at the British Association meeting at Bristol 1955 are given.—B. G. B.

Scientific Study of the Techniques of Mechanical Production. P. Nicolau. (*Rev. Univ. Min.*, 1955, 9th series, **11**, Sept., 413–419). A short review of the scientific approach to engineering construction is presented.—B. G. B.

Air Pollution Problems. G. D. Clayton. (*Trans. Amer. Found. Soc.*, 1955, **63**, 181–190). The legal aspect of air pollution in the United States is discussed and the State laws and proposed Federal Bills on the subject are summarized. The health and control aspects of pollution are very briefly considered.—B. C. W.

Purification of Metals by New Physical Techniques. F. Montariol. (*Chim. Ind.*, 1956, **75**, Jan., 57–64). The principles of the zone melting technique are described. A number of applications of the technique are explained.—B. G. B.

Statistical Techniques in Iron and Steel Making. L. Dor. (*Rev. Tech. Luxembourg*, 1955, **47**, Oct.-Dec., 235–243).

Accuracy of Time Records: Technical Statistics as an Aid in Operational Research. A. Stumpf. (*Stahl u. Eisen*, 1955, **75**, Dec. 1, 1640–1645).

A Radioactive Counter Suitable for Prospecting in Brazil. G. Kegel. (*Bol. INT*, 1953, **4**, May, 18–22). [In Portuguese]. Most of the conventional counters (scintillation counters or ionization chambers) are not suitable for use in Brazil because of the difficulty in obtaining special batteries or because of their high cost. An apparatus is described which is cheap to mass-produce, contains materials readily available and is easily adjustable. Dry "flash-light" batteries are used.—R. S.

Heat Stress in Industry. T. Bedford and Barbara E. Tredre. (*Trans. Inst. Min. Eng.*, 1955, **115**, Dec., 209–240). A comprehensive account of recent work on heat physiology and human fatigue under hot and humid conditions is reported. Data obtained from the steel are included in the discussion.

Operational Research: The Front-line Scientist in the Management Team. Sir C. Goodeve. (*Iron Steel*, 1955, **28**, Dec., 667–668). The impact of science on industrial management is discussed and the value of operational research methods is stressed.—G. F.

Applied Thermodynamics: Some Numerical Examples. J. W. Evans. (*Iron Steel*, 1955, **28**, Nov., 501–504; Dec., 643–645). The author considers a number of elementary numerical examples of thermodynamics which illustrate the general principles and also demonstrate the practical significance of thermodynamics in iron and steel making. The basic equations on which the examples rest are discussed.—G. F.

Uranium Content of Two Iron Meteorites. G. W. Reed and A. Turkerich. (*Nature*, 1955, **176**, Oct. 22, 794–795). Recent work has failed to find any uranium in two iron meteorites.

Westinghouse Metallurgical Plant at Blairsville, Pa. W. M. Trigg. (*Indust. Heating*, 1956, **23**, Jan., 70–82). A description is given of the layout and equipment at a large laboratory for pilot-plant investigation.—A. D. H.

Science and Technical Enterprise in the Iron and Steel Industries. H. Schenck. (*Tetsu to Hagane*, 1955, **41**, July, 831–837). [In German]. An address given by the President of V.d.Eh. to the Iron and Steel Institute of Japan. The author considers in particular recent criticisms voiced in Britain regarding the value of advanced physico-chemical research in technological development and shows that while this type of research does not, and cannot be expected to, result in the emergence of new processes, it can help considerably in process and production quality control.

Survey of the German Iron and Steel Industry and Its Research Problems. H. Schenck. (*Stahl u. Eisen*, 1955, **75**, Oct. 20, 1358–1361). The German industry is compared with others, and economic problems are reviewed. Unfavourable natural conditions are described as a spur to efforts in fundamental research. This is conducted without hope of long-term gain. Great progress is sometimes made in practice while scientific theory lags behind, but it would be a mistake to reduce fundamental investigation on this account. The extension of knowledge would be enormously facilitated by friendly co-operation between engineers and scientists, however, for the excessive overlapping of research work in different countries is a brake on progress.—A. C.

NEW PUBLICATIONS

American Iron and Steel Institute. "*Annual Statistical Report*, 1955." La. 8vo, pp. v + 136. New York, 1956: The Institute.

American Society of Mechanical Engineers. "*Problems and Control of Air Pollution.*" Proceedings of the First International Congress on Air Pollution held in New York City, March 1–2, 1955, under the sponsorship of the Committee on Air-Pollution Controls of the American Society of Mechanical Engineers. Edited by Frederick S. Malette. 8vo, pp. vi + 272. Illustrated. New York, 1955: Reinhold Publishing Corp.; London: Chapman & Hall, Ltd. (Price 60*s.*).

American Society for Testing Materials. "1955 *Book of ASTM Standards, Including Tentatives.*" Part 2. "*Non-Ferrous Metals.*" (A triennial publication). 8vo, pp. xxxii + 1482. Illustrated. Philadelphia, Pa., 1955: The Society.

American Society of Tool Engineers. "*Die Design Handbook.*" 8vo, pp. vii + 732. Illustrated. New York, Toronto, London, 1955: McGraw-Hill Book Co., Inc. (Price $14.50).

Broda, E. u. T. Schönfeld. "*Technische Anwendung der Radioaktivität.*" Pp. 208. Illustrated, Berlin: VEB Verlag Technik, 1956. (Price 10 DM.).

Charles, J. A., W. J. B. Chater, and J. L. Harrison. "*Oxygen in Iron and Steelmaking.*" 8vo, pp. xii + 309. Illustrated. London, 1956: Butterworths Scientific Publications. (Price 42*s.*).

Dearden, John. "*Iron and Steel To-Day.*" Second edition. 8vo, pp. 271. Illustrated. London, 1956: George Cumberlege, Oxford University Press. (Price 12*s.* 6*d.*).

Donald, M. B. "*Elizabethan Copper. The History of the Company of Mines Royal* 1568–1605." 8vo, pp. vii + 405. Illustrated. London, 1955: Pergamon Press, Ltd. (Price 60*s.*).

Fuller, Dudley D. "*Theory and Practice of Lubrication for Engineers.*" 4to, pp. 432. Illustrated. New York and London: John Wiley and Sons and Chapman and Hall, 1956. (Price $10.50).

General Electric Company, Ltd. "*A Handbook on Belt Conveyor Design.*" Compiled by the Technical Staff, Materials Handling Department, Fraser and Chalmers Engineering Works, in Association with Hewitt-Robins Inc., New York. 8vo, pp. 148. Illustrated. Erith, Kent, 1956: The Company. (Price 30*s.*).

Houdremont, Eduard. "*Handbuch der Sonderstahlkunde.*" Dritte, verbesserte Auflage. Unter Mitarbeit von Hans-Joachim Wiester. La. 8vo, illustrated. Erster Band, pp. xvi + 1–874; zweiter Band, pp. vii + 875–1538. Berlin, Göttingen, Heidelberg, 1956: Springer Verlag; Düsseldorf: Verlag Stahleisen m.b.H. (Price (two volumes) DM. 220.–).

Levin, Ernest M., Howard F. McMurdie, and F. P. Hall. "*Phase Diagrams for Ceramists.*" Editor, Margie K. Reser; Consulting Editor, Herbert Insley. La. 8vo, pp. [ii +] 286. Illustrated. Columbus, Ohio, 1956: American Ceramic Society. (Price $10).

Meetham, A. R. "*Atmospheric Pollution. Its Origins and Prevention.*" Second revised edition. 8vo, pp. ix + 302. Illustrated. London and New York, 1956: Pergamon Press. (Price 63*s.*).

Organisation for European Economic Co-operation. "*The Iron and Steel Industry in Europe.*" La. 8vo, pp. 122. Paris, 1956. O.E.E.C. (Price 9*s.*).

Society of Automotive Engineers. "1956 *SAE Handbook.*" La. 8vo, pp. 1172. Illustrated. New York, 1956: The Society. (Price 85*s.* 6*d.* (Library rate)).

Sutherland, K. L., and I. W. Wark. "*Principles of Flotation.*" Second edition. 8vo, pp. xv + 489. Illustrated. Melbourne, 1955: Australasian Institute of Mining and Metallurgy (Inc.). (Price 90*s.*).

United Nations. "*The European Steel Market in* 1955." Folio, pp. vi + 100 + xii. Geneva, 1956: U.N.O. (Price 5*s.* 6*d.*).

Verot. "*New Applications of 'Fibrage Integral.' C.G.F. Continuous Grain-Flow Process.*" 4to (mimeographed), pp. 14. Illustrated. Saint-Chamond, 1956: Compagnie des Ateliers et Forges de la Loire.

Wilson, W. Ker. "*Practical Solution of Torsional Vibration Problems.*" With Examples from Marine, Electrical, Aeronautical, and Automobile Engineering Practice. Volume One, "*Frequency Calculations.*" Third edition, revised. 8vo, pp. xxxii + 704. Illustrated. London, 1956: Chapman and Hall, Ltd. (Price 105*s.*).

"*Quin's Metal Handbook*, 1955." Editor, K. V. Henderson. 42nd year. La. 16mo, pp. 719. London [1956]. Metal Information Bureau Ltd. (Price 25*s.*).

SIR CHARLES GOODEVE, O.B.E., D.Sc., F.R.S., F.I.M.

CHARLES GOODEVE was born in Canada in 1904. He entered Manitoba University in 1919 and after graduation spent three years engaged on research on electro-chemistry. In 1927 he was awarded a scholarship to University College, London, where he remained until the outbreak of World War II. He was appointed Lecturer in Physical Chemistry in 1930, and in 1937 became Reader in Chemistry. At University College his researches were mainly concerned with physical chemistry, and especially with photochemistry, absorption spectra, and reaction kinetics. He was elected a Fellow of the Royal Society in 1940.

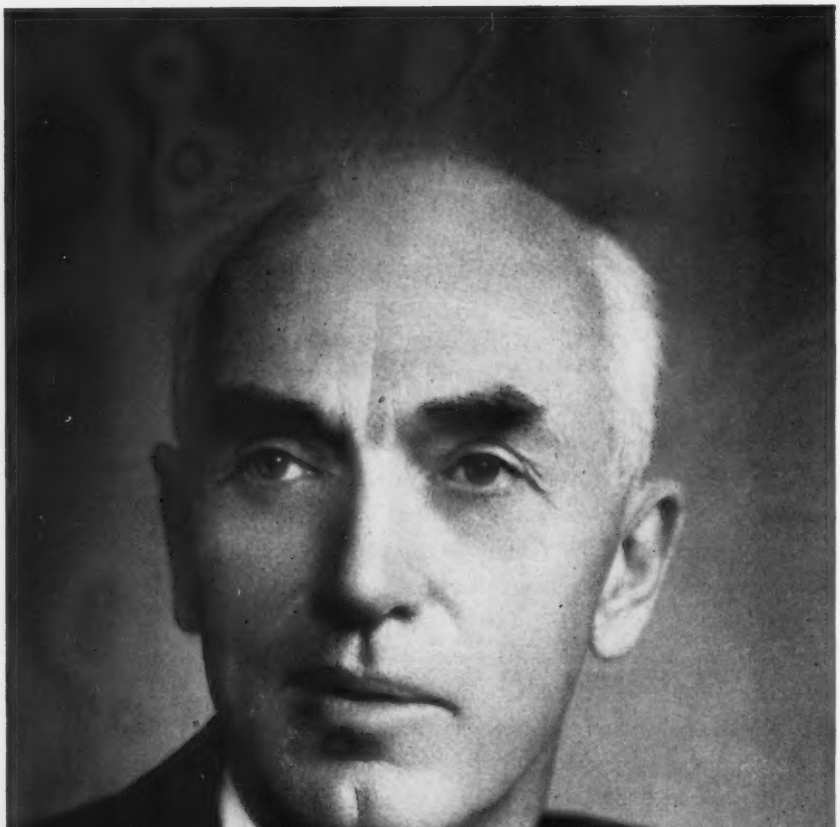
During World War II, he served in the Royal Navy. He played a responsible part in countering the magnetic mine, and later developed and produced the "Hedgehog" anti-submarine weapon. From 1942 onwards Commander Goodeve, as Deputy Controller, was in effective control of the whole research and development programme of the Royal Navy, and it was for his services in this connection that he was knighted in January, 1946.

Sir Charles left the Admiralty to become Director of the British Iron and Steel Research Association on its foundation in 1945. To this was later added the honorary post of Research Director to the British Iron and Steel Federation. His appointment reflected the increasing emphasis on the physical aspects of the science of metals. He has resisted the administrative demands of this post sufficiently to contribute to knowledge of the physical chemistry of metallurgical processes: he was President of the Faraday Society from 1950 to 1952, and took the chair at the Society's meeting in Toronto in 1952. He was appointed President of the Chemistry Section of the British Association for the Advancement of Science in 1956. His services to the iron and steel industry and to chemistry were further recognized in August, when the University of Sheffield conferred on him the honorary degree of Doctor of Science.

Sir Charles early recognized the importance to industry of operational research, and was the first Chairman of the Operational Research Society. As a member of the Research Advisory Council to the British Transport Commission, he has a special interest in the application of operational research to road and railway problems.

Since April, 1953, Sir Charles has been a member of the Advisory Council on Scientific Policy to the Lord President of the Council. He is also a member of the Technical Advisory Panel of the Iron and Steel Board and Vice-Chairman of the Parliamentary and Scientific Committee.

As Director of B.I.S.R.A., Sir Charles has been an Honorary Member of Council of The Iron and Steel Institute since 1945, and in May, 1956, he was elected a Vice-President.



Sir Charles Goodeve, O.B.E., D.Sc., F.R.S., F.I.M.

Vice-President